PRODUCTION PLANNING APPROACH FOR IMPLEMENTING SUSTAINABLE BUILDING PROJECTS

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DECLARATION

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ABSTRACT

Sustainable buildings have received effective responses for application in recent years and are gradually becoming a part of mainstream in the construction industry. However, the process of delivering a high sustainable-performance building has led to a more complex construction practice by the increment of specialized processes involved. In great extent, the complexities associated are deemed to be related to the different emerging needs that current construction management systems are unable to meet effectively. Whilst a vast of studies exist related to sustainable buildings such as environmental performance assessment and green design, it appears that little study has addressed the implications that the new practice has brought to fundamental and highly important areas like planning and construction site management. In this study, Production Planning Process (PPP) is considered essential in helping to make sure that resources are capable of meeting the planned schedule whilst sustainable practice is implemented. Otherwise the requirements and constraints imposed by sustainable building practice can impact construction sequencing and timing, resulting in workflow variability that can lead to exceed the estimated construction time and cost of the building. A few researchers have opined on the possible implications related to the inefficient response of traditional PPP when subjected to complex projects as sustainable buildings, but little factual data from construction site was adopted to support their conclusions.

This study aims to measure the performance of the PPP with incorporating sustainability attributes and propose a system for its improvement when implementing and delivering sustainable building projects. Multiple research methods are adopted. Firstly, interviews and site visits were conducted for collecting first hand information on the perceived shortcomings and needs of the current PPP when implementing sustainable building projects. Secondly, extensive literature review was conducted for exploring current and newly applied theories in the PPP in the construction industry. Thirdly, a system was developed to measure the performance of the PPP, to reveal how construction activities with relation to sustainable deliverables affect production performance in construction site and to identify the main causes for workflow variability that can lead to its improvement. The system was developed by the integration of Lean Construction principles and metrics and Six Sigma methodology. A comprehensive case study is used to demonstrate how the proposed system works through three main stages, namely, first stage (Define and Measure), second stage (Analysis and Improve) and third stage (Control). The case study consisted in a residential project in Hong Kong which includes two high-rise towers that received Platinum certification according to the Building Environmental Assessment Method (BEAM). Results from the case study confirmed the importance of effective measures communicating the performance of PPP as these were considerable different from what the managers previously perceived. It was also demonstrated the improvement of the PPP performance by implementing Lean Construction principles and how these were effectively implemented by the integration with Six Sigma methodology. The integration allowed a systematic implementation that provided sufficient information supporting the decision-making process when attempting to improve the PPP. Important improvements in the reliability of the PPP were achieved and successfully controlled over time. The system also demonstrated that the production performance and causes of variability in the

workflow of construction activities with relation to sustainable deliverables are different from those activities with no relation. While the difference in the production performance is not considerable significant, the difference in the causes of variability is. It is demonstrated that sustainable building projects present different and unique sources of variability that affect the overall production performance of construction activities. The findings of this study imply the intrinsic importance contained in the reliability of PPP when implementing sustainable building projects and validate the effectiveness of the system proposed in this research for improving its performance.

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Introduction

CHAPTER 1: INTRODUCTION

1.1 Introduction

In line with the promotion of sustainable development, it is recognized that the building sector holds a great importance to all human activities as well as ecological environmental health. Thus, sustainable buildings have emerged as high performance properties that are expected to have less impact on the environment. However, complexities associated with the sustainable building practice have been found. The complexities are related to many new components introduced with varying demands in comparing to traditional buildings, resulting in uncertainties and difficulties in achieving the designated purposes from the sustainable building practice. The effects related to these complexities include inability to deliver materials at the right time, rework, changes in priority, design errors and project delays (Thomas and Sanvindo, 2000; Horman et al. 2004). Such effects are mainly attributed to the inefficiency and ineffectiveness of current building planning and delivery processes which are best suitable for conventional types of buildings (Riley, et al. 2004; Lapinski et al. 2005).

This research appreciates that the production planning process (PPP) accounts the key to the efficiency of the delivery processes in sustainable building projects. This is due to the significant relation of the PPP to the ability to effectively and efficiently accomplish the sustainability objectives related to day-to-day construction activities of sustainable building projects. However the traditional PPP practice applied in construction appears unresponsive to the needs of sustainable building projects. The traditional PPP is related to unreliable production plans with great variability, which prolongs cycle times and decreases the outputs of the project by increasing the amount of waste in the construction process (Ballard, 2000; Koskela, 2000). It is especially in complex projects as the case of sustainable building projects when the deficiencies in the traditional PPP are exacerbated (Alarcon et al., 2005). Therefore, the focus of this research is to find out a solution to improve the current PPP by overcoming the effects of the complexities for attaining sustainability goals in sustainable building projects. This has led to the development of a system for improving the PPP in sustainable building projects, namely PLAN-SB as the core of this study. PLAN-SB has the main purpose of improving the efficiency and effectiveness of the PPP in the implementation and delivery of sustainable building projects. The system is developed based on Lean Construction principles and Six Sigma methodology. Lean Construction principles are proposed for leading to a more efficient PPP which also integrates what client values (e.g. sustainability). And, Six Sigma methodology is proposed for conducing to a more effective PPP and assisting to deliver high quality plans. PLAN-SB is implemented for (1) evaluating the extent to which the use of Lean Construction and Six Sigma can improve the effectiveness and efficiency in the PPP during the implementation of sustainable building projects and (2) identifying the main causes behind the effective and efficient achievement of sustainability goals during construction stage in sustainable building projects.

1.2 Research Background

It is now more than 35 years since the UN Conference on Human Environment in Stockholm suggested that the post-war economic development model based on continuous growth in consumption, and fuelled in part by the drive to 'develop' the so called ‘developing countries’, may exceed certain basic environmental limits, and in the process upset the delicate balance of the ecosystem on which the human species depends for its survival (UN 1972). This understanding has led to the gradual formulation of ‘Sustainable Development’ as a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but in the indefinite future (WCDE, 1987). Over the years the concept of Sustainable Development has evolved from its initial concerns of ecological sustainability and incorporated economic sustainability and social sustainability.

In the process of achieving sustainable development goals, it has been well recognized that the construction industry has an important role to play (CIB 1999; Horvath 1999). In many countries, this single industry accounts for up to half of all raw materials extraction by weight, as well as being the largest producer of solid waste, estimated at 40% (UNEP 2002). In particular, building industry is responsible for the consumption of several and large amount of natural resources mainly during construction and operation stages. According to the OECD (2003) buildings consume some 30% of the world’s resources, 10% of water and around 40% of the world’s energy. In addition, buildings are growing in number as the recent human development has seen a transitional demographic shift from predominately rural based societies to urban centers (Newman and Kenworthy 1999, O'Meara 1999). More than 50% of the global human population currently lives in cities and urban population will continue to increase as total human population will increase, predicted to peak at approx 9-11billion people by 2070 (UN 2008). Building sector, therefore, holds great importance to all human activities, as well as ecological and environmental health.

In line with the promotion of sustainable development, sustainable buildings have emerged as high performance properties that are expected to reduce their impacts on the environment and human health. The principles of sustainable buildings mainly seek to optimize site potential and energy use, protect and conserve water, use environmental friendly products, enhance indoor environmental quality and optimize operational and maintenance practices (Cole 2000). Whilst the positive impacts of sustainable buildings have been proved (Berman 2001), the process for accomplishing a high sustainability performance in a building is often regarded as a more complex, dynamic and pressed practice for time and cost (Horman et al. 2006). The main reasons are related to the increment of specialty sub-contractors, professionals, resources, materials and construction methods involved in these projects in order to meet specific requirements defined in sustainable building assessment and certification systems such as BREEAM (BRE 2007), LEED (USGBC 2005), BEAM (Beam Society 2004). It could be argued that sustainable features within a project may offer flexibility and benefits to the industry, however it is also argued that these features have resulted in fragmented decision-making causing cost in the form of delays, reworks and waste of resources (Howard et al. 1989; Odeh and Battaineh 2002). To some extent, this could be attributed to a lack of consensus when planning the day-to-day activities since each specialty subcontractor will follow their own production plans. This effect has been found particularly in large and complex building projects before (Dubois and Gadde 2002; Egan 1998). In addition, general contractors which suppose to lead and coordinate the production planning process, often adopt a contract-brokering role rather than the role of coordinating the project (Tommelein and

Ballard 1997). Thus, activities for sustainable features cannot be collectively implemented, resulting in extra resources consumption.

The association of complexities of sustainable building projects for implementing and delivering the projects request for effective management systems. It appears nevertheless that current construction management systems have weaknesses and are inefficient in meeting the new challenges. Previous studies have investigated and concluded that successful exponents of sustainable building practice will be those that possess the organizational culture and management expertise and have the ability to assess and maximize the sustainable potential of a construction project (Eid 2004; Lapinski et al. 2005; Pulaski et al. 2006). It has also been argued that the successful delivery of sustainable buildings not only requires incremental change in practice but also a revolution in approach, a shift of perspective, which needs to be reflected in a future generation of construction management techniques (Bae and Kim 2008; Klotz et al. 2007; Lapinski et al. 2006). Other studies have manifested that sustainable building practice as all emerging practices has a 'learning curve' and that all shortcomings in the current construction management systems will be overcome with gained experience and without radical and sudden changes in the current practice (Boecker 2003; Scheuer 2007). These provide two types of constructive arguments. However, conclusions are mainly based on perceptions of practitioners with varied experience in delivering sustainable building projects, and the learning curve is based on the comparison of different projects without regarding their unique characteristics (e.g. scale, sustainable performance achieved and project stakeholders). Therefore, it is considered more proper to know if current construction management systems meet these emerging needs by measuring their performance when implementing and delivering sustainable building projects. The use of performance measurements makes possible the analysis of attributes of a process necessary for improving its efficiency and effectiveness (Koskela 1992). Consequently, the purpose of this research is to find out a vehicle for the performance measurement and improvement of a particular process (i.e. the Production Planning Process (PPP)) when implementing and delivering sustainable building projects.

1.2.1 Why focusing on Production Planning Process (PPP)?

It has been well appreciated that the main functions of project management are planning, organizing, staffing, coordinating, directing and controlling (Patrick 2004). Planning is the first of the many steps involved in project management. If planning were not done meticulously, other management functions including project execution and control would become very difficult. Of equal importance is the process of production planning (Gidado 1996). This process involves the planning of day-to-day production activities and controlling them to accomplish project objectives. Thus, a good and reliable PPP determines the success of all the following functions.

According to studies carried out by Atkins (1994), inefficiencies in planning are one of the main weaknesses of the construction sector. Other studies have revealed that relevant amount of resources are wasted due to different actors within a project following their own plans, which seldom match with one another. According to Persson and Solberg (1994) time gains of around 50% are possible by making simple changes. And, Rostad et al. (2005) found that 50% of time spent on site is non-productive and 80% of the purchase orders raised for a contract are rush orders. All these are due to improper planning practice. These findings are echoed by the results of a survey carried out by the FMI and the Construction Management Association of America (CMAA) (2008) suggesting that owners of construction companies and service providers in the construction industry perceived planning and budgeting as the area with the majority opportunities for improvement. In fact, the survey (FMI/CMAA 2008) also revealed that sustainability is perceived as the least area for opportunities for improvement as seen in Figure 1.1. The discrepancy might be explained by the increasing complexity of today's projects. Therefore, from the perspective of contractors and service providers, priority is given to those areas as planning and budgeting for helping to deliver the projects more efficiently and effectively.

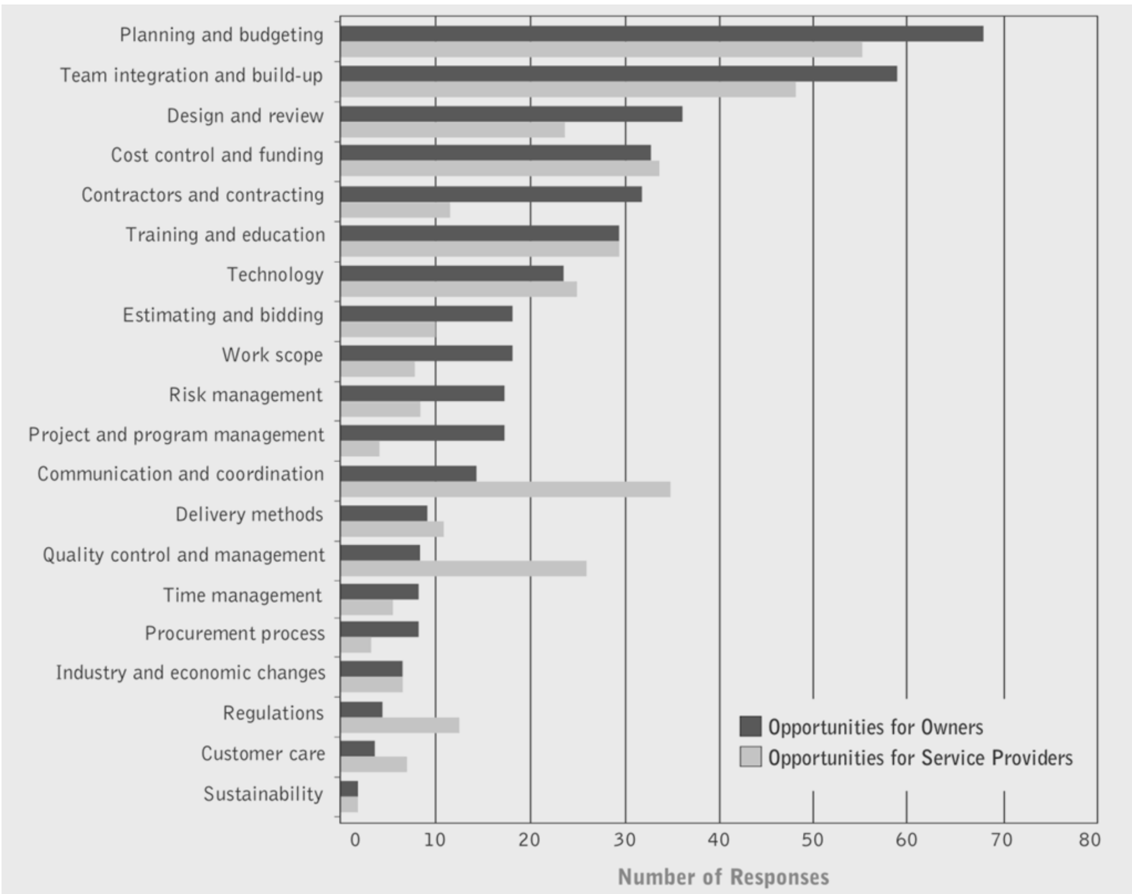

Figure 1.1 Where are the opportunities for improvement? (FMI/CMAA 2008)

The accuracy of production plans highly depends on the information required for its preparation. Generally this information includes master plans, drawings, estimations, progress reports, forecastings, etc. The requirements related to the sustainability of the buildings need to be addressed in the construction plan and must be included in the schedule. These specific requirements will impact the procurement, construction, project closeout and commissioning (Glavinich 2008). Resources procurement for sustainable building projects (e.g. green materials, specialized human resources, equipment) also impacts the sequencing of construction activities as well as activity timing. As a common practice, plans and specially production plans are prepared based on previous experience, regarding lead times of materials delivery, workers performance, equipment performance, etc. (Zozaya et al. 1989). Therefore, it is more difficult to plan activities that involve new requirements from which there is lack of experience. As a result, these difficulties are manifested making production plans less reliable and with greater variability. “No variability” means production is “reliable” (Tommelein et al. 1999). Variability can induce fluctuating and unexpected conditions, making objectives unstable and obscuring the means to achieve them. According to Koskela (2000), variability in the workflow often prolongs cycle times and decreases system throughput by increasing the amount of waste in a process. Waste which Liker (2004) defines as activities which absorb resources without adding value to the costumer or as nonvalue-added activities (NVA), a term used in the manufacturing industry to define the work not required by the ideal operating process (Zangwill and Kantor 1998).

Variability sources typically are inability to deliver materials at the right time and the right place, equipment flow, information flow, rework, waiting, changes, delays, erroneous information, defects, preparation time, transportation, idle time, and inspection (Thomas et al., 1989, Thomas et al., 1999, Thomas and Sanvido, 2000, Zangwill and Kantor, 1998). Variations in construction output or in production performance provide an indication of levels of workflow variability and these appear to be a good determinant of good and poorly performance projects (Gonzalez et al. 2008; Thomas et al. 2002).

Therefore, the PPP is considered essential in helping to make sure that resources are capable of meeting the planned production schedule; otherwise the requirements and constraints imposed by sustainable building practice can impact the construction sequencing and timing, resulting in variability that can lead to exceed the estimated construction time and cost of the building.

1.2.2 What should we expect from a Production Planning System?

According to Smith and Ow (1990), tools to support production planning must be able to efficiently generate schedules that reflect the actual constraints and objectives of the construction environment, and allow these schedules to be incrementally revised over time in response to unexpected execution circumstances. Furthermore, Koskela (2000) stated that a production planning should follow three principles: (1) assignments should be sound regarding the prerequisites, (2) realization of assignments is measured and monitored, and (3) causes for non-realization are investigated and those causes are removed.

In this sense, typical methods used for supporting the planning process in construction as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are considered good for early planning stage, but are seldom use for the PPP once projects start. The plans generated by using these methods generally involve high-planning requirements, which are too high to justify use when conditions rapidly change (Howard et al. 1989). According to Tommelein et al., (1999) CPM schedule's misrepresentation of the workflow is the key reason why most superintendents use it only as a loose guide for executing work. Therefore, these plans only serve as reference to recognize milestones but are not suitable for those on site programming the day-to-day activities. In addition, Howell and Koskela (2000) listed the deficiencies in the assumptions and theory of current production management compared with the necessities of modern projects, as seen in Table 1.1.

Table 1.1 Deficiencies in the assumptions and theory of current project management

Category	Assumption and Theory	Modern Projects
Uncertainty in scope and method	Low	High
Relationships between activities	Simple, Sequential	Complex, Iterative
Activity boundary	Rigid	Loose
Performance criteria	Activity-based	Need to consider flow between activities
Production management	Not considered	Needs to be considered
Model	Transformation	Needs to be viewed as a combination of transformation, flow and value generation

Source: (Howell and Koskela 2000)

Therefore, what should be expected from a PPP is to efficiently control time through proper planning, scheduling, and monitoring; planning determines what work is to be done and in what sequence; scheduling decides task duration and timing; monitoring confirms the realization of assignments against the schedule and forecast. And, its main objective is to manage the production of progress, not productivity.

1.3 Research propositions and objectives

The overall aim of this research is to measure the performance of the production planning process with incorporating sustainability attributes and to propose a system for its improvement when implementing and delivering sustainable building projects.

Literature review, interviews and site visits were carried out for understanding the sustainable building practice and the problems encountered during the implementation and delivery of sustainable building projects in the construction stage. Following a literature review of Lean Construction and Six Sigma, which investigates whether the use of these methods are appropriate for meeting the aim of this research. Literature review form the theoretical foundation of this research and reveal the necessity and originality of this study.

A research proposition that has emerged from a literature review on sustainable building practice is:

1. Current production planning practices applied for delivering sustainable buildings are not enabling sustainability goals to be achieved efficiently and effectively.

Another research proposition that has emerged from the literature review on Lean Construction and Six Sigma is:

2. Lean construction principles can lead to a more efficient production planning process and integrate client values (e.g. sustainability). On the other hand, Six Sigma can conduce to a more effective production planning process and assist to deliver high quality plans.

The above two propositions lead to the formulation of the main research hypothesis:

- The adoption of a production planning system based on Lean Construction principles and Six Sigma methodology could improve the efficiency and effectiveness in the implementation and delivery of sustainable building projects.

In line with the research propositions and research hypothesis, the main research objectives are:

- To measure the production performance of activities with relation to sustainability attributes and compare with those without relation.
- To evaluate the extent to which the use of lean construction and six sigma can improve effectiveness and efficiency in the PPP during the implementation of sustainable building projects
- To identify the main causes behind the effective and efficient achievement of sustainability goals during construction stage in sustainable building projects.

In order to achieve the research objectives the following tasks need to be completed:

- To develop a production planning system that can be used as a tool to investigate the effect of using Lean Construction principles and Six Sigma methodology in sustainable building projects
- To develop a framework of how the proposed production planning system can be implemented in sustainable building projects
- To measure, analyze and control the effects of using Lean Construction principles and Six Sigma methodology
- To record the causes affecting the production performance of activities and identify the ones related to sustainability attributes of the project

1.4 Thesis Structure

This thesis is composed of eight Chapters. ***Chapter 1*** introduces this research and presents the research background and the research propositions, hypothesis and objectives. ***Chapter 2*** reviews the literature and relevant research done by others. This review includes sustainable building practice, construction planning and production process, Lean Construction and Six Sigma. ***Chapter 3*** explains the research methodology adopted for this study and why particular methods were chosen. A methodology comprising different research methods including direct observations, interviews and action research was constructed. ***Chapter 4*** introduces the development process of PLAN-SB. The process includes the integration of Lean Construction and Six Sigma, the selection of metrics and tools, and the development of the PLAN-SB implementation framework. ***Chapter 5*** contains the description and results from the implementation of PLAN-SB. The implementation was divided in three main stages namely, First Stage (Define and Measure), Second Stage (Analysis and Improve), Third Stage (Control). ***Chapter 6*** presents a comparative analysis for identifying the causes affecting production performance of activities with direct relation to sustainable deliverables (i.e. ‘G activities’) and those with no direct relation (i.e. ‘O activities’). ***Chapter 7*** discusses on the findings obtained from the implementation of PLAN-SB in Chapter 5 and the comparative analysis in Chapter 6. ***Chapter 8*** presents summaries and conclusions of this study. The significance and contribution of the research to knowledge, limitations of the study and recommendations for future research are also presented.

Chapter 2

Literature Review

CHAPTER 2: LITERATURE REVIEW

2.1 Sustainable Building

2.1.1 What is a sustainable building?

A sustainable building is ‘a high-performance property that considers and reduces its impact on the environment and human health’ (Yudelson 2008). The American Society of Testing and Materials (ASTM 2006) defined it as ‘a building that provides the specified building performance requirements while minimizing disturbance and improving the functioning of local, regional, and global ecosystems both during and after its construction and specific service life’. A typical definition by Kibert (2008) describes a sustainable building as ‘healthy facilities designed and built in a resource-efficient manner, using ecologically based principles’. Sustainable buildings are driven by a confluence of rising public concerns about global climate change, cost and availability of energy sources, and the impact of the built environment on human health and performance. The concept has received tremendous interest in the last few years, which has become one of the mainstream topics in construction industry.

Previous studies have addressed various characteristics for sustainable buildings (Cole 2005; Kwong 2004), which can be highlighted as follows:

- Optimize site potential (reduce impact on ecosystems, required transportation, and energy use through considerations of location, orientation, and landscaping)
- Optimize energy use (reduce loads, increase efficiency, and consider renewable energy)

- Protect and conserve water (minimize runoff, use efficiently, and consider reuse)
- Use environmentally preferable products (materials which have reduced impact on human health and environment when compared to equally performing materials)
- Enhance indoor environmental quality (maximize day-lighting and views, control moisture and ventilation, and minimize volatile organic compounds (VOCs))
- Optimize operational and maintenance practices (take measures to minimize the environmental impacts of building maintenance and to ensure the building will operate as intended).

2.1.2 Sustainable building assessment and certification

There are now numerous sustainable building assessment and certification systems worldwide (Cole 2006; Ding 2008). These systems are used to evaluate and differentiate buildings that achieve sustainable design levels beyond local regulation and design code standards. The assessment and certification schemes remain ahead of the current building practice, setting performance targets in line with the trajectories required for the sustainability needs of each country (Cole 2005). Sustainable building assessment and certification systems, such as BEAM (Beam Society 2004), BREEAM (BRE 2007), GBTool (IISBE 2007), and LEED (USGBC 2005) provide a very broad coverage of environmental, economic and social issues, which are associated to be relevant to sustainability. Different versions of these systems are developed for assessing new or existing buildings.

These tools use a mix of objective and subjective data in application. Most of them use subjective scoring or weighting systems based on indicators that distil the information and provide useable sustainability measures. Some require external auditors, and most yield certificates or labels indicating a building's performance. Most of these systems have been developed to transform the design goal, and specific performance objectives and provide a framework to assess the overall design. These systems are used by design professionals for making design decisions, material and equipment selections and in determining the performance of particular aspects of a building (Seo et al. 2005). Warnock (2007) has proposed to place the sustainable building assessment and certification systems as the core instruments as to achieve sustainability in the building practice since these provide the focus for all actors and brings together the various instruments that are utilized to achieve it.

Several city authorities now require sustainable building certifications for public and private building projects, both for refurbishment and for new builds. For instance, Seattle City has improved its urban sustainability performance by requiring all new buildings larger than 5,000 ft2 to meet new state LEED building ratings (OSE 2000). Similar commitments have been demonstrated in the UK by authorities in Leeds and Manchester, requiring new major developments to meet minimum BREEAM standards (WEF 2009). However, recent concerns are related to sustainable buildings that achieve significant sustainability performance or a particular certification level at design completion but do not maintain this level during occupation. Mechanisms such as granted certification one year after completion would function to ensure buildings meet the initial design criteria, and further regular evaluation would ensure buildings continue to operate as designed.

2.1.2.1 Assessment indicators and certifications

Indicators

The assessment of sustainability performance of buildings requires indicators related to sustainability evaluation aspects of the building according to the sustainable building assessment and certification systems. For instance, these indicators include the ones related to energy, indoor environmental quality, space, waste management, and water use. Indicators are established by benchmarks or checklists, and can be qualitative or quantitative. ISO (2004) states that qualitative indicators for the assessment of sustainability performance in buildings can be expressed in a quantitative way by means of ratings or scorings. The evaluation of qualitative indicators can be made by consensus or by agreement (Haapio and Viitaniemi 2008). In the case of quantitative indicators, these defined metrics and values are benchmarked according to local, national and international building performance standard codes.

Certifications

Sustainable building assessment and certification systems communicate the overall assessment results by means of a certification label (Cole 2006). There are different certification labels and these correspond to the level of sustainability performance achieved in a building. For instance, BEAM (Building Environmental Assessment Method), the sustainable building assessment and certification method in Hong Kong, certifies a building as ‘Platinum’ when a building has achieved an outstanding sustainability performance, and as ‘Bronze’ when a moderate sustainability performance has been achieved (Beam Society 2004).

2.1.3 Benefits for adopting a sustainable building practice

According to previous studies by Building Design & Construction (2003), McGraw Hill Construction (2005) and Turner Construction (2005), the increasing willingness to meet sustainability in buildings projects are based on the following main benefits:

1. Lowering lifecycle costs, such as energy efficiencies and productivity
2. Being part of an industry that values the environment
3. Expanding my business with green building clients
4. Benefit from publicity
5. Higher return on investment
6. Awards for green building
7. Reinforcing the green brand of an organization
8. Satisfying government
9. Improving staff health, staff satisfaction and productivity levels
10. Avoiding building obsolescence

2.1.4 Reasons for discouraging a sustainable building practice

Identified reasons for not adopting a sustainable building practice are multiple in number and represent an important challenge for the promotion of this practice. Resistance to change has been manifested in any important proposal where new practices are involved and these studies have proved that sustainable building practice is not the exception. Earlier studies by Building Design & Construction (2003), McGraw Hill Construction (2005) and Turner Construction (2005) have identified varied reasons discouraging sustainability in building projects; and the main reasons are as follows:

1. Higher construction costs
2. Lack of awareness of benefits
3. More complex construction
4. Risk associated with changing from traditional processes of design and construction
5. Changed site practices and behaviours
6. Payback too long
7. Difficulty quantifying benefits
8. Perceived lack of tenant demand
9. Longer design time using integrated design teams

The 1999 CIB report (1999) listed the main reasons for not adopting a sustainable building practice from the perspective of processes and management:

1. Professional and institutional inertia defending the status quo
2. Lack of understanding of the problem among construction professionals
3. Inadequate or defective vehicles for participation by the stakeholders
4. Market delay
5. Insufficient data
6. Lack of communication between sectors
7. Lack of client buy-in
8. Political insecurity (government electoral periods limit the horizon)

The California Integrated Waste Management Board (CIWMB) (2001) also identified several reasons from the administrative, organisational and fiscal perspective that impede the full-scale implementation of sustainable buildings as follows:

1. Incomplete integration
2. Lack of life-cycle costing
3. Insufficient performance and operating standards
4. Lack of incentives and insufficient technical information

2.1.5 Higher construction cost as the principal reason for discouraging sustainable building practice

There has been a widespread perception that sustainable buildings are substantially more costly than conventional ones and therefore may not be justified from a cost benefits perspective. This perception has been the single largest obstacle to the effective widespread adoption of sustainable building practice. According to Berman (2001), US developers interviewed in 2001 estimated that sustainable buildings cost 10% to 15% more than conventional buildings. Blueprint's studies (2001) revealed that many sustainable building applications are prematurely considered as "unproven or too costly". Consulting – Specifying Engineer (CSE) (2002) pointed out that the perception of sustainable buildings as more expensive facilities is pervasive among developers and will take time to overcome.

Although the premium cost of sustainable buildings is perceived among developers to be as high as about 10% to 15%, more recent studies (Boecker 2003; Kats 2003) have shown that the achievement of sustainable building certifications may not necessarily mean high levels of premium cost. Studies have exposed that cost associated with sustainable design and construction may exceed to traditional practice 1% of construction costs for large buildings and 5% of costs for small buildings. Higher performance levels of sustainable buildings (e.g., LEED Silver, Gold, or Platinum standard) involve some additional capital costs (Yudelson 2008). Kats (2003) found that on average, the premium cost for sustainable buildings is about 2%. The study by Davis Langdon (2004) suggests no statistically significant difference between a population of LEED projects and comparable non-LEED projects of otherwise similar quality. Turner Construction (2005) evaluated the evidence on cost premiums from multiple studies and found that cost premiums for LEED certified projects will range from 0.8% for certified-level to 11.5% for platinum-level projects.

Critically, the increased cost premiums associated with implementing practice of sustainable buildings is a major barrier for owners to pursue sustainable building objectives. However, a number of exemplary sustainable buildings are emerging to suggest that the requirements of sustainable projects do not have to lead to increased project costs. For example, facility owners like Toyota Motor Sales have been able to deliver LEED Gold-certified facilities without a first-cost premium (Pristin 2003).

2.1.6 Principal reasons for higher construction cost in the application of sustainable buildings

The understanding of incremental cost of sustainable buildings is important, since the most important factor in building development and construction world is cost. Yudelson (2008) identified some of the elements in design and construction decisions that may add cost to sustainable building projects, as shown as follows:

1. Level of sustainability certification sought

2. Stage of the project when the decision is made to seek sustainability
3. Project type
4. Experience of the design and construction teams in green design and sustainable buildings
5. Types of green technologies adopted in the project
6. Level of direction from the owner in establishing priorities for green measures and a strategy for including them
7. Project geographic location and climate

Pulaski (2003) added that some of the obvious premium costs related to sustainable buildings are higher materials price, and more expensive technologies. Other premium costs are related to design and construction processes and activities. Majority of sustainable building projects have been performed with many of the same delivery processes as conventional type of buildings. Traditional delivery processes take a limited account of the expanding scope of services, cross-disciplinary interaction, and complex design analysis required for delivering sustainable building projects (Lapinski et al. 2005). An increase in project budgets is necessary for overcoming the deficiencies of traditional practice for sustainable project delivery.

Horman et al. (2004) opined that not just technology and materials but processes play a key role in successfully delivering a high performance sustainable building on budget and on time. Delivering a high performance sustainable building without an adverse first-cost impact of the project is a big challenge. Generally, these sustainable building projects demand a more integrated design approach for engaging complex design analysis, energy modelling, and system optimization (Riley et al. 2004). Additionally, new and unfamiliar materials adopted for sustainable buildings can affect construction lead times, procurement systems and construction processes. Furthermore, if a sustainable building certification is planned, extensive documentation will add time and cost to the completion of the project.

The experience gained is another important factor affecting the cost and efficiency in the delivery process of sustainable building projects. Boecker (2003) reported that sustainable buildings get less expensive over time. Building organisations have a "learning curve" for implementing sustainable buildings, the design and construction process for the first sustainable building of a client or design/architectural firm or contractor is often characterized by significant learning curve costs, and design schedule problems such as late and costly design changes. Cost estimators may add uncertainty factors for new green technologies they are not familiar with, and these can compound and further inflate cost estimates. However, the majority of these additional costs are due to the required time to integrate sustainable building practices into projects execution (Kats 2003).

2.1.7 How the implementation of sustainable buildings affects current construction practice?

The complexities related to sustainable buildings and how this innovative practice affects the current practice are manifest in the fact that sustainable buildings contain many new components in comparing to traditional buildings, resulting in numerous outputs and bring together many factors with varying demands (Roodman and Lensen 1995). Besides the physical aspects, sustainable buildings attract intricate legal attention, bear on economic implications, and have significant cultural, social and environmental ramifications (Bourdeau et al. 1998; Warnock 2007).

However, whilst all these complexities related to sustainable buildings exist, and the adoption of the practice is still on voluntary basis, sustainable buildings have been already widely adopted. This may be due to two primary causes: (1) an increasing awareness that sustainable buildings tend to be more economical to operate from the perspective of building life cycle, and (2) the implementation of new government policies that help to promote sustainability characteristics in new building projects (Kwong 2004; Yates 2001). The driving forces behind the sustainable building practice are very strong. The research firm McGraw-Hill Construction (2009) predicted that green buildings will represent 20-25 percent of new commercial and institutional construction works by 2013. Marsh Mercer Kroll (MARSH) (2009) reported that despite the economic recession, the number of sustainable building projects across the U.S. continues to grow. However, these tendencies are not that strong in developing countries such as China, where the rapidly expanding $300 billion a year construction industry currently gives little consideration to sustainable building practice (Boardman 2009).

Developing sustainable buildings is a client driven practice with a strong tendency. Other stakeholders in building industry need to respond and adopt the strongly emerging practice. In line with this, professionals in the industry need to understand the effects that may be associated to these projects and to change current practice for meeting additional requirements needed in the delivery process of sustainable buildings. Among these requirements, Riley et al. (2004) highlighted the key elements including the intense interdisciplinary collaboration between construction stakeholders, highly complex design analysis, and careful selection for material and performance assessment systems. Therefore, advance management methods for meeting these requirements need to be adopted. For instance, supply chain activities such as off-site construction, modulation and “plug-and-play” solutions can reduce site waste leading to faster construction and improved performance (Kibert 2008). Effective sustainable building performance assessment and certification systems are also needed to take into account building material components, their life cycle analysis and responsible procurement (Cole 2005).

In promoting sustainable buildings, there is no doubt that an increased emphasis must be placed on not just the “what” questions of sustainable buildings, but also the “how” and the “who”. Emphasis should be given to the existing project processes in delivering sustainable buildings. Current building delivering processes are developed best suitable for conventional types of building. Previous studies suggest that these traditional building delivery processes are unresponsive to the needs of sustainable building projects (Lapinski et al. 2005). These processes are frequently associated with wasteful rework, delays, changes, and overproduction (Horman et al. 2004). Process waste can both undermine the achievement of sustainable outcomes and limit the business case for sustainability (Lapinski 2005; U.S. GSA 2004).

Professionals experienced in sustainable building development often reveal that process efficiencies are the keys to the low-cost and effective delivery of sustainable buildings (Horman et al. 2006). Therefore, there is a need to improve those building delivery processes that are not enabling sustainability goals to be achieved effectively and efficiently. In this sense, it is well appreciated that planning is the first of many steps involved in delivery process of a building. If planning were not done accurately, following processes including project execution and control would become very difficult (Patrick 2004). Therefore the following section reviews the current construction planning and production process.

2.2 Construction planning and production process

The management of construction projects requires the understanding of both project management and production management. However, existing practice and research has mainly focused to project management aspects when referring to management of construction projects and say very little, if anything at all, about the production management aspects. The knowledge developed to manage projects is to large extent unique due to the unique nature for a construction project (PMI 1996).

For implementing a construction project, there are three levels of schedules: a master schedule, lookahead schedules or progress schedule, and weekly work plans (Salem et al. 2006). The main differences among these three levels of schedules are in two aspects: the size of the scheduling window and the level of detail. Each type of schedule serves a different purpose.

2.2.1 Master schedule

A master schedule is produced during the front end planning and covers an entire project (Koskela 1999). Master schedules are composed of a group of work packages. A work package is a sub-element of construction project, for which both cost and time data are collected for project status reporting. And the combination of all work packages constitutes a project's work breakdown structure (Halpin, 1985). The work packages are often the lowest level items of a Work Breakdown Structure (WBS)(PMI 1996).

The generation of a mater schedule, especially for a large and complex project can be a difficult task. Therefore, a large number of computer-aided tools have been developed to assist project managers to develop and maintain a master schedule. For instance, Primavera Project Planner (2010) or Microsoft Project (2010) are computer tools widely applied by project managers for planning and overseeing construction projects in the process of administering contracts. These tools also help to generate a common representation, which depict predecessor relationships between where each activity has a given duration, and unit resources allocated to it. This representation facilitates effective communication between different participants involved in a construction project regarding who should be doing what work and when.

However, master schedules are considered insufficient when it comes to supporting production planning and control, which will guide and provide detail instructions to those who are performing construction work in the field. The productivity of field workers depends on the availability of resources, and this availability is governed by production planning and resources flow prior to installation, including the timely procurement, release or delivery, and allocation of the resources (Tommelein and Ballard 1997). Furthermore, master schedules do not represent the resources availability, skill level, or productivity of the crew that is actually going to carry out the work. Therefore, master schedules are generally used as reference for defining the milestones of the project, for understanding the dependency of activities and for generating lookahead schedules and weekly work plans (Ballard and Howell 1998).

2.2.2 Lookahead schedules

It is generally appreciated that a big problem field workers often face is coping with discrepancies between anticipated and actual resource availability. Numerous uncertainties (e.g., ambiguities in design drawings, errors in take-off, fabrication errors requiring rework, delays in shipment, damage during handling, etc.) affect the flow of resources prior to their application (Tommelein and Weissenberg 1999). Accordingly, field workers have developed their own, special-purpose planning methodologies named lookahead schedules, whilst the application of lookahead plans are with varying degrees of success (Ballard 1997). Existing field-level planning methodologies vary considerably from one construction superintendent or foreman to the next. Regardless of the format of lookaheads, existing planning tools appear to have no mechanism for screening scheduled activities against criteria such as definition, soundness, sequence, sizing, and learning (Ballard 2000).

2.2.3 Weekly work plan

Weekly work plans are the most detailed plans adopted by the foremen of specialty contractors who will actually carry out the work. These specialty contractors can provide knowledge regarding (1) development of creative solution, (2) additional needs associated with construction processes, (3) fabrication and construction capabilities, and (4) supplier's lead-times and reliability (Gil et al. 2000). The information regarding construction capability includes availability of labor, equipment, and tools. In terms of labor, specialty contractors know the skill level, productivity, and availability of each worker. Weekly plans allow the foremen to estimate the duration of each activity more realistically as compared to durations developed for the master schedule. The estimate for activity duration in master plan is based on an assumed process that involves various people and professionals who may not have first-hand knowledge on site. Thus, the quality of weekly plans is better when the planning authority is pushed down (Laufer 1987).

2.2.4 Production planning process (PPP)

The meaning of the term 'Production' at its most generic sense is synonymous with "making" (Ballard 2000). A production process can be defined as the method or the steps involved in making a product (Dennis 2007). In the building industry, production processes typically include site preparation, erection of building, finishing and delivering the end construction product (Eccles 1981; Gann 1996). Therefore, the project planning process in building projects includes defining and organizing the work to be accomplished. The most common way of doing this is by using the three levels of planning explained above. However, in this research, the planning of construction activities at site level for a period of time is referred to as 'Production Planning Process (PPP)', and is different from project planning. Production planning is the process of organizing and developing a plan of daily actions to be executed to complete a production process. This process is affected by on a number of factors and variables and implemented by a number of key people who have been or will be associated with the project (Peterson et al. 1993).

In addition to the process of planning explained above, planning for a production type setting would include coordination of trade contractors, planning of material supply chain, continuous availability of work and contingencies for possible uncertainties involved in completing a task. Production planning should provide effective organization, control throughout the project, and workflow reliability such that each individual production activity work starts and finishes according to the plan.

Therefore, it is appreciated that the production planning process (PPP) accounts as an important delivery process in construction activities, and its improvement can represent the effective and efficient accomplishment of sustainability objectives related to day-to-day construction activities of sustainable building projects. Hence, there is a need for alternative approaches for the improvement of the PPP and these alternatives will be investigated by applying advanced methodologies.

It is appreciated that the application of Lean production principles in construction has been proven effective to reduce waste and improve process performance in complex construction projects and production environments (Höök and Stehn 2008; Thomas et al. 2002). Similarly, the application of Six Sigma methodology in the construction industry has derived important results related to the achievement of high quality processes and variability control (Buggie 2000; Han et al. 2008; Pheng and Hui 2004; Stewart and Spencer 2006). Therefore, these two advanced methodologies are revised in the following two sections for their potential use for improving the PPP.

2.3 Lean Construction

2.3.1 Introduction to the definition of Lean production

Lean production is a design and production management system developed in the 1950's by Engineer Ohno at Toyota. The aim of Lean Production is to shorten the cycle time to get products to market by minimizing waste. According to engineer Ohno, this new production philosophy should provide the follows (Howell 1999; Ohno 1988):

1. A uniquely custom product,
2. Instant delivery with minimum inventory, and
3. Production with zero waste.

Unlike 'craft production' or 'mass-production system', Lean production has the qualities of both: custom-oriented goods and lower production cost (Carreira 2005). The key elements and characteristics of lean production methodology include multi-skilled workers, stopping the production process by any worker when faults are found, no rework area, pull planning system, flexible and automated machines, and transparency of production systems (Hopp and Spearman 1996).

Lean principles have been applied successfully worldwide in the automobile industry. Manufacturers like Toyota have strived to adopt the principles, which is 100% value-added work with zero or minimum waste (Liker 2004). These lean principles are being increasingly employed in many other industrial sectors with great success. In recent years, increasing number of construction companies have decided to implement lean principles in their business activities. Guided by research efforts, lean production has been promoted to the construction industry. There are reports that the companies applying Lean production principles receive good returns on their investments, specifically in the areas of waste reduction in on-site production activities (Alarcon et al. 2005; Eckhouse 2003).

2.3.2 What is Lean Construction?

The great success of Lean production in the manufacturing industry (Womack et al. 1990; Womack and Jones 1996) has led to the exploration and then the development of a lean theory in construction, known as Lean Construction. Lean Construction is a translation and adaption of lean production principles and practices to the end-to-end design and construction processes. Koskela et al. (2002) defined Lean Construction as "way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value in construction". Lean Construction introduced production system as a new way to view construction projects with two important recognitions (1) dependences and variations along supply and assembly chains in construction projects and (2) managing product and process uncertainties (Howell 1999). The current construction practice, which generally follows the principles of project management, identifies activities only as transformation activities. This receives criticisms such as by Koskela (1992), proposing to classify site activities in two categories, namely transformation and flow. Later, Koskela (2000) added the perspective of value-creation to the characteristics of activities giving the classification as transformation, flow and value activities.

Lean Construction aims to better meet the customer needs while using less of everything imposed in the application of production management principles. Lean Construction is a new project delivery system that can be applied to any kind of construction project but is particularly suited for complex, uncertain, and quick projects (Howell 1999). The implementation of lean principles in construction represents differences from the common practice and advantages are multiple. For example: there is a clear set of objectives for the delivery process, it focus at maximizing performance for the customer at project level, activities and processes are designed and it uses production control throughout the life of the project. Contrarily, in the current form of production management in construction it is assumed that the customer value has been identified and therefore the process is activity centred with more focus on optimizing the project activity by activity.

A variety of studies and techniques have emerged from lean thinking and applied to construction. For instance, there are studies investigating the use of lean construction principles for assuring a continuous improvement in industrialized housing production . Some addresses increasing safety commitment on construction site ; Perhaps the majority of studies in this discipline focus to reduce waste and increase value in day to day activities mainly in the design and construction stage (Salem et al. 2005; Thomas et al. 2003; Thomas et al. 2002). Among this studies one of the most well accepted techniques in practice is the 'Last Planner System' developed by Ballard and Howell (2007). The system aims to help contractors to effectively and reliably assign work tasks for completion in order to reduce workflow variability. Although the results of applying lean principles in construction have not matched those achieved in the manufacturing industry, the benefits have been proved.

2.3.3 Last planner system

Lean production principles lead to the development of Last Planner System (LPS) for managing construction planning, by emphasizing process efficiency and focusing on achieving objectives (Ballard and Howell 1994; Faniran et al. 1997). The system refers to the process of creating a lookahead and a weekly work plan through lean construction planning techniques which can increase workflow reliability (Ballard and Howell 2003). One of the principal characteristics of the LPS is its ‘pull planning system’ basis. Conventionally, work assigned to a crew is considered as ‘should do’ work, the capacity of the crew to perform that ‘should-do’ work is defined as ‘can-do’ work, and the work the crew actually commits as ‘will-do’ work (Ballard and Howell 1994; Wang et al. 1996). In the traditional ‘push planning systems’ as shown in Figure 2.1, which are the most commonly used to manage production in construction projects, the ‘can-do’ is not considered and a crew is assigned to work without making sure that the work can be done (de Toni et al. 1993). Contrarily, the LPS system follows the ‘pull planning system’ principles (See Figure 2.2) in order to effectively increase workflow reliability.

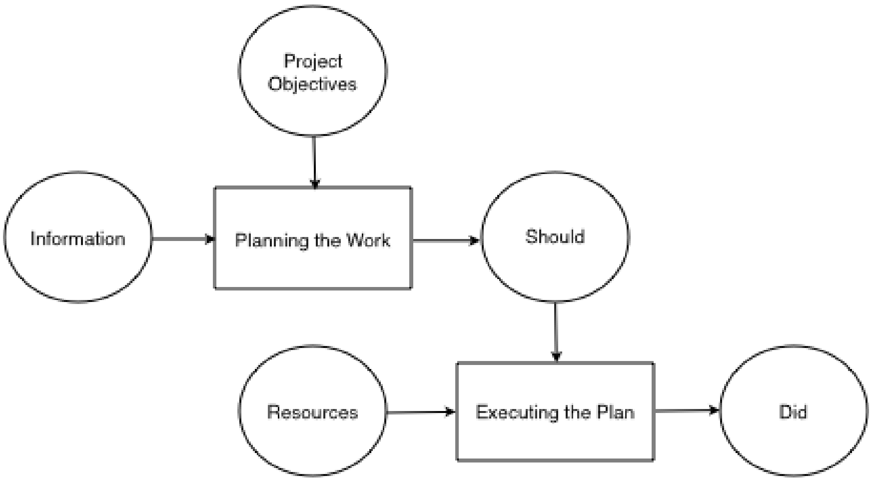

Figure 2.1 Push planning system

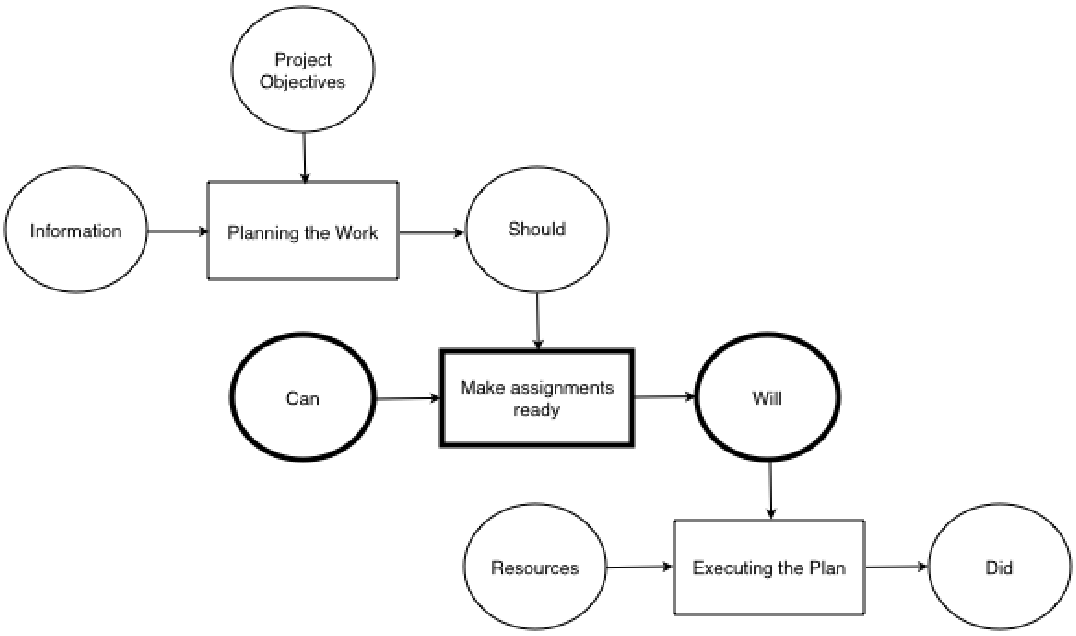

Figure 2.2 Pull planning system

Planning for assignments as done in the LPS, is performed after work assignments are subjected to a constraint analysis that ensures no obstacles will prevent execution. Figure 2.3 shows the steps involved in the Last Planner System.

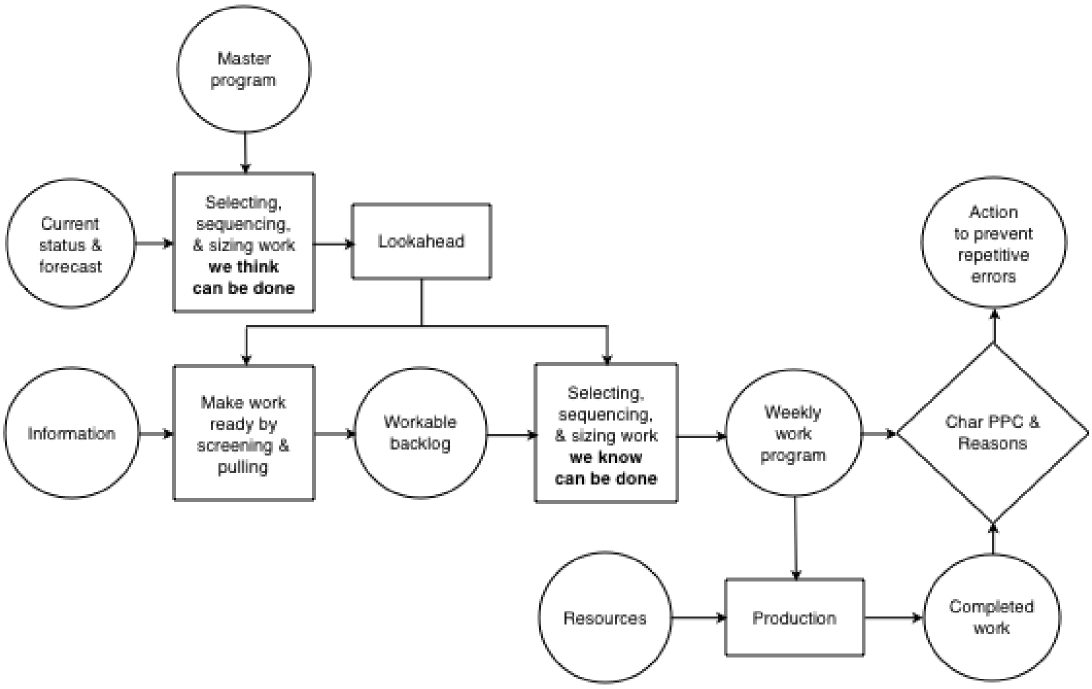

Figure 2.3 The Last Planner System (Naim and Barlow 2003)

As illustrated in Figure 2.3, master schedules are the main inputs in the system as these involve the development of logic and sequence of the project that helps to identify the commitments throughout the project execution. The next two levels of schedule involves greater detail of planning where the project components are tested for logic and the work is divided into phases to identify the constraints of related work. According to the Lean Construction Institute, each level of planning in the LPS has a very specific purpose (Lean Construction Institute 1999).

The purpose of master schedule is to:

1. Demonstrate the feasibility of completing the work within the available time
2. Display an execution strategy that can serve as a basic coordinating device
3. Determine when long lead items will be needed

The purpose of the lookahead schedule is to:

1. Shape work flow in the best achievable sequence and rate for achieving project objectives that are within the power of the organization at each point in time
2. Match labour and related resources to work flow
3. Produce and maintain a backlog of assignments for each frontline supervisor and crew, screened for design, materials, and completion of perquisite work at the CPM level
4. Group together work that is highly interdependent, so the work method can be planned for the whole operation, and
5. Identify operations to be planned jointly by multiple trades.

The purpose of the weekly work plan is to:

1. Identify make ready actions and assessing their feasibility prior to making assignments so as to shield production units from uncertainty.
2. Make best use of the production unit's capacity and acknowledge individual's differences in light of the schedule loads.

2.3.4 Lookahead planning

Lookahead planning as shown in Figure 2.4 takes its inputs from traditional planning techniques. Usually, the lookahead involves consideration of potential assignments for the upcoming 4 weeks based on the project characteristics (Lean Construction Institute 1999). The activities are exploded from master schedule into a level of detail, appropriate for an assignment on a weekly work plan. This typically yields multiple assignments for each activity. As each assignment appears in the lookahead window (a 4 weeks period), it is subjected to constraint analysis to make sure it is ready to be executed (Ballard 2000).

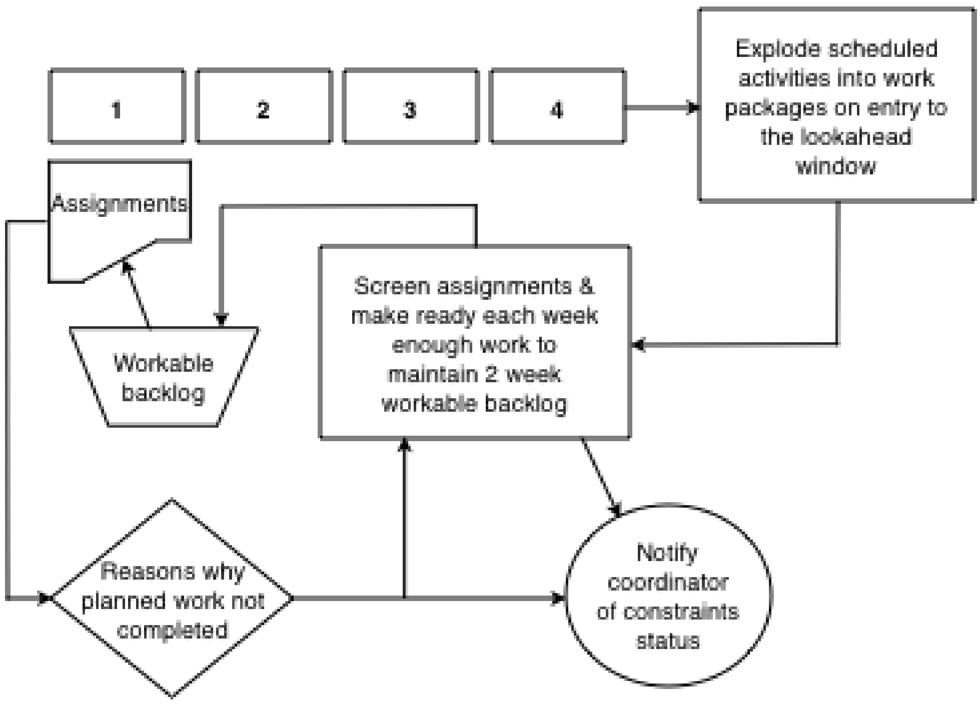

Figure 2.4 Lookahead planning (Ballard and Howell 2003)

Assignments that are made ready for execution enter into a workable backlog. The assignments entering the workable backlog are all constraint free and in the proper sequence for execution. Ballard (2000) suggests that assignments to executives are quality assignments when they satisfy the following criteria:

1. Definition: Assignments are specific enough so that the right type and amount of materials can be collected and work can be coordinated with other trades.

2. Soundness: Assignments are workable; that means all constraints are removed (e.g. materials are on hand, the design is complete, the prerequisite work is complete, etc.).

3. Sequence: Assignments are selected from those that are sound in priority order and in constructability order. Additional, lower-priority assignments are identified as workable backlog, that is, additional quality tasks are available in case assignments fail or productivity exceeds expectations.

4. Size: Assignments are sized to the productive capability of each crew or sub-crew, while still being achievable within the plan period.

If the last planner finds activities that do not meet these criteria, these would not be allowed to move forward (Ballard 2000). The last planner should maintain a backlog of work ready to be performed, with assurance that everything in the workable backlog is indeed workable (Ballard 2000). Weekly work plans are formed from the workable backlog. Such assignments help improve the productivity of those who receive them and increase the reliability of workflow between the production units. The LPS can be viewed as a needed supplement to traditional project management for better production. The analysis of reasons for plan failure reveals more information regarding how the production system actually functions and what can be done to improve it.

2.3.5 Percent Plan Complete (PPC)

To assess the quality of the assignments made, a metric know as a Percent Plan Complete (PPC) is introduced. PPC is calculated as a ratio of the number of assignments completed to the total number of assignments planned in a given period of time. PPC is expressed as a percentage with a range between 0% - 100%. In general, the higher the PPC, the more reliable the production planning system is. A PPC of 100% means all the work assigned is completed as planned and it is the best-case scenario. A PPC value less than 100% means there is a problem with the PPP. According to Ballard (2003), PPC values are highly variable and usually range from 30% to 70% without lean implementation. A good performance is above 80% and a poor one is below 60%. Working teams with experience on the system are able to maintain a performance above 85% (Ballard 1999).

2.4 Six Sigma

2.4.1 What is Six Sigma?

Six Sigma was developed by Motorola in 1985 as a system that would help them to achieve near-perfect products (Howell and Macomber 2002). The main goal of the system is to reduce variability by using diverse statistical methods and tools for identifying and reducing variability causes. Linderman et al. (2001) defines Six Sigma as “an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods to make dramatic reductions in customer defined defect rates”.

Six Sigma was developed by industry practitioners at Motorola who were not primarily interested in academic contributions. Therefore, it is not surprising that little literature related to Six Sigma is devoted to theory as note by Linderman et. al., (2003). Well-accepted quality management theories, including Statistical Quality Control (SQC), Zero Defects and Total Quality Management (TQM), have been key players for many years (Ahire et al. 1995; Linderman et al. 2003), while Six Sigma is one of the more recent quality improvement initiatives , and it gains popularity and acceptance in many industries (Breyfogle 1999; Lederer and Karmarkar 1997). However, Six Sigma differs from other quality programs in its rigorous methodology that demands detailed analysis, fact-based decisions, and a control plan to ensure ongoing quality control of a process. Six Sigma changes the way a company thinks by teaching fact-based decision making to all levels. Since its initiation at Motorola, many companies including GE, Honeywell, Sony, Caterpillar, and Johnson Controls have adopted Six Sigma and obtained substantial benefits (Pande et al. 2000; Stamatis 2003a).

2.4.2 Six Sigma Principles

The principles of Six Sigma can be best expressed into the following six themes (Pande et al. 2000; Snee 2004):

1. Genuine focus on the customer. The statistical tools and profits gained by the implementation of Six Sigma seem to get the most publicity, however the emphasis on quality by really understanding what adds value to customers accounts as the most remarkable element of Six Sigma.
2. Data and fact-driven management or metrics for decision-making. "Management by facts" is taken to a higher level by the implementation of Six Sigma. Instead of basing business decisions on opinions and assumptions, Six Sigma builds the foundation of decision making by using metrics (i.e., sigma value) in building up key measures that represent and calculate the success of everything an organization does.
3. Process focus, management, and improvement. Six Sigma positions the process as the key vehicle of success, covering design of products and services, measuring performance, improving efficiency and customer satisfaction, etc.
4. Proactive management. Proactive means action in advance of events rather than reacting to them. An example of proactive management in Six Sigma is the focus on eliminating defects at the source instead of trying to manage the defect or problem after it has occurred. It tries to solve why the bad results are occurring.

5. Boundless collaboration. Boundless means working to break down corporate barriers and to improve teamwork up, down, and across organizational lines.
6. Drive for perfection, tolerate failure. Although these two ideas sound contradictory, they are actually complementary. The bottom line is that any company that makes Six Sigma its goal will have to keep pushing to be more perfect while being willing to accept and manage occasional setbacks.

2.4.3 DMAIC

Six Sigma uses two different frameworks according to the purpose of its implementation. One framework includes Define, Measure, Analyze, Improve, and Control (DMAIC) for process improvement. Another framework composes of Define, Measure, Analyze, Design, and Verify (DMADV) for new product and service development (Pande and Holpp 2002; Pande et al. 2000). DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements, and applies technology for continuous improvement. The production planning process (PPP) in construction is not a new process in construction, however it is a process that changes from contractor to contractor and from project to project. Therefore, the framework for the improvement of an existing process (i.e. DMAIC) better meets the needs related to the purpose of improving the PPP of sustainable building projects. In Table 2.1, the key steps involved in DMAIC are shown.

Table 2.1 The key steps involved in DMAIC

Steps	Key processes
Define	Define the requirements and expectations of the customer Define the project boundaries Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs Develop a data collection plan Collect and compare data to determine issues and shortfalls
Analyze	Analyze the causes of defects and sources of variation Determine the variations in the process Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements Develop a strategy to monitor and control the improved process Implement the improvements of systems and structures

Source: (Eckes 2001; Przekop 2006)

2.4.4 Sigma Level

Sigma (σ) is the symbol for standard deviation in statistics. Thus, a six sigma level means having all the products produced within six standard deviations of the mean and a six sigma yield level represents 99.99966% of products produced without defect (Pande and Holpp 2002). This can be easily explained as to bring the defect rate of a process or a product as low as 3.4 Defects Per Million Opportunities (DPMO), which is expressed as 6σ level. Table 2.2, introduces a simplified sigma conversion table where values of Yield and DPMO for sigma levels from 1 to 6 are presented.

Table 2.2 Simplified sigma conversion table

Sigma level	Yield = percentage of items without defects	DPMO
1	30.9	690,000
2	69.2	308,000
3	93.3	66,800
4	99.4	6,210
5	99.98	320
6	99.9997	3.4

Source: (Pande and Holpp 2002)

The sigma concept of measuring defects was started as a way to develop a universal quality metric that could be applied regardless of product complexity or dissimilarities between different products or processes (Pande and Holpp 2002). Higher sigma values indicate better products or processes with fewer numbers of defects per unit of product or service. Products produced at a Six Sigma level of quality operate virtually defect-free. Through Six Sigma, every measurable can be compared on the same platform through converting yields or DPMO to sigma level, no matter how different they may be (Thawani 2004). All the organization needs to do is to set out guidelines in determining measurables during implementation.

2.4.5 Six Sigma implementations

Implementation of Six Sigma principles can be mainly divided into two different types, manufacturing and non-manufacturing business, described as follows:

2.4.5.1 Manufacturing business

Cases of successful manufacturing companies that have adopted Six Sigma can be found in the literature. The authors describe how the respective companies implement Six Sigma, giving insights into issues of perceived best practices (Chowdhury 2000; Koch et al. 2004). Motorola was the first organization to use the term Six Sigma in the 1980s as part of its quality performance measurement and improvement program. Six Sigma has been successfully applied in other manufacturing organizations such as Boeing, DuPont, Ford Motor, Seagate, Texas Instruments, GE, etc. (Connolly 2003; Connor 2003; Fuller 2000).

2.4.5.2 Non-manufacturing Business

Healthcare sector

Healthcare services are one of the major active nonmanufacturing contexts in which Six Sigma has been adopted, with the majority of cases taking place in USA (Pande et al. 2000). Six Sigma principles and the healthcare sector are very well matched because of the healthcare nature of zero tolerance for mistakes and potential for reducing medical errors. Some cases explain how Six Sigma improves healthcare service quality by reducing medical errors and increasing patient safety (Benedetto 2003; Sehwail and DeYong 2003).

Financial services sector

In recent years, finance and credit department are pressured to reduce cash collection cycle time and variation in collection performance to remain competitive. Typical Six Sigma projects in financial institutions include improving accuracy of allocation of cash to reduce bank charges, automatic payments, improving accuracy of reporting, reducing documentary credits defects, reducing check collection defects, and reducing variation in collector performance (Buck 1998; Doran 2003). Bank of America is one of the pioneers in adopting and implementing Six Sigma concepts to streamline operations, attract and retain customers, and create competitiveness over credit unions. It has hundreds of Six Sigma projects in areas of cross-selling, deposits, and problem resolution. Bank of America reported a 10.4% increase in customer satisfaction and 24% decrease in customer problems after implementing Six Sigma (Roberts 2004; Stamatis 2003b).

2.4.6 Six Sigma in construction

The use of Six Sigma in the construction industry is relatively new. It has been argued that the great number of variables and uncertainties encountered in construction operations probably makes the 6σ level an inappropriate goal and therefore an inappropriate quality system for construction projects (Kwak 2006; Pheng and Hui 2004). However, it is appreciated that the tangible benefits expected from the implementation of Six Sigma in construction should be related to evaluate the project's performance improvement as an extension of the traditional approaches for achieving a high level of quality process.

Some of the first approaches of Six Sigma implementation in construction found in the literature are related to the achievement of high quality processes and variability control (Buggie 2000; Han et al. 2008; Pheng and Hui 2004; Snee 2000) to identify and prevent rework and defects (Stewart and Spencer 2006); to enhance the commissioning process (Eckouse 2003). Beyond the sole use of Six Sigma, Kroslid (2006) and George (2002) proposed the combined use of Six Sigma and lean principles as a way to achieve an outstanding quality performance and Abdelhamid (2002) looked at this approach for reducing the variability in lean construction by using six sigma principles. However, there are few cases where research has been conducted considering the defect rate involved in a specific construction management process where quantitative goals are defined for measuring performance improvement as it is attempted in this study.

2.4.7 Success factors in Six Sigma implementation

From the literature, some success factors for implementing Six Sigma are identified and presented as follows (Abdelhamid 2003; Antony and Banuelas 2002; Banuelas and Antony 2002):

1. Management commitment and involvement
2. Understanding of Six Sigma methodology, tools, and techniques
3. Linking Six Sigma to business strategy
4. Linking Six Sigma to customers
5. Project selection, reviews and tracking
6. Organizational infrastructure
7. Cultural change
8. Project management skills

9. Liking Six Sigma to suppliers
10. Training

2.4.8 Lean Six Sigma

The root of both Lean and Six Sigma reach back to the time when the greatest pressure for quality and speed were on manufacturing (Johnson and Swisher 2003). Lean emerged as a method for optimizing automotive manufacturing; Six Sigma evolved as a quality initiative to eliminate defects by reducing variation in processes in the semiconductor industry. Therefore, it is not surprising that the earliest combined implementations of both methods (Lean Six Sigma) emerged from the manufacturing organizations like GE, Caterpillar, and Lockheed Martin (George 2002).

Lean Six Sigma is a business improvement methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital (George 2003). The fusion of Lean and Six Sigma improvement methods is required because (Arnheiter and Maleyeff 2005):

- Lean cannot bring a process under statistical control
- Six Sigma alone cannot dramatically improve process speed or reduce invested capital
- Both enable the reduction of the cost of complexity

Ironically, Six Sigma and Lean have often been regarded as rival initiatives. Lean enthusiasts noted that Six Sigma pays little attention to anything related to speed and flow (Pyzdek and Keller 2009; Womack and Jones 2003), while Six Sigma supporters pointed out that Lean fails to address key concepts like customer needs and variation (Carreira 2005; Harry and Schoroeder 2000). Both sides are right. Yet these arguments are more often used to advocate choosing one over the other, rather than to support the more logical conclusion that we blend Lean and Six Sigma (Flinchbaugh 2007; Pande et al. 2000). Therefore, what sets Lean Six Sigma apart from its individual components is the recognition that you cannot do "just quality" or "just speed," you need a balanced process that can help an organization focus on improving service quality, as defined by the customer within a set time limit.

2.5 Can the implementation of Lean Construction and Six Sigma contribute to sustainability?

It has been argued that both Lean construction and Six Sigma are aligned to the goals of sustainable construction (Ferng and Price 2005; Nave 2002), and these relations are mainly attributed to the aims of these two methodologies for identifying and eliminating waste and for adding value to the client (Bae and Kim 2008; Degani and Cardoso 2002; Huovila and Koskela 1998). Therefore, if the client values sustainability (e.g. client requires a sustainable building certification) Lean Construction and Six Sigma could be able to help to maximize the efficiency and effectiveness of processes leading to attain sustainability goals. Moreover, recent studies are going beyond the traditional approach and these are looking to the improvement of sustainable projects delivery processes by adopting Lean principles (Horman et al. 2004; Lapinski et al. 2006). The relation of these methodologies with sustainability is bringing varied research opportunities for contributing to the efficiency and effectiveness of the implementation of sustainable construction practice. For instance, Penn State University has highly adopted this approach by what they call ‘Lean and Green Initiative’ in its research and education program (Klotz et al. 2007).

Chapter 3

Research Methodology

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research propositions and hypothesis

Research propositions

Before the selection of a research strategy it is necessary to determine the research topic, propositions, and purpose. The topic of this research is engineering management; more specifically, improving the PPP of sustainable building projects. The propositions driving this research are:

- Current production planning practices applied for delivering sustainable buildings are not enabling sustainability goals to be achieved efficiently and effectively. This research proposition is formulated from literature review on sustainable building practice.
- Lean construction principles can lead to a more efficient production planning process and integrate client values (e.g. sustainability). On the other hand, Six Sigma can conduce to a more effective production planning process and assist to deliver high quality plans. This research proposition is formulated from literature review on Lean Construction and Six Sigma.

Research hypothesis

Based on the two research propositions, the main research hypothesis is:

- The adoption of a production planning system based on Lean Construction principles and Six Sigma methodology could improve the efficiency and effectiveness in the implementation and delivery of sustainable building projects.

The main purpose of this research is to evaluate the performance of the PPP with incorporating sustainability attributes, and to propose a system for its improvement when implementing and delivering sustainable building projects.

Existing studies suggest that evaluation and performance measurement are types of applied or action research (Horman et al. 2006). These typically pursue improvement of practices and rate effectiveness against objectives by conducting exploration, description, and explanation during an implementation process. Performance measurement and improvement often go together, especially when this involves the implementation and evaluation of new practices, as is the case of this study. Moreover, improving practice requires understanding what works and what does not work, and in a greater extent as possible, understanding why works and why does not work. Consequently, the purpose of this study includes determining the extent to which the adoption of a production planning system based on Lean Construction principles and Six Sigma methodology is effective and why it is or is not effective.

3.2 Research Strategy

According to Robson (1989) three traditional research strategies are survey, experiment, and case study. Generally, engineering management theses, which pose claims about some aspect of engineering management action use surveys as research strategy to collect data and apply statistical analyses to test the adequacy of their claims. This methodology works from a sample of a population to claims the findings about the population itself by statistical generalization. In this research, a survey is adopted in the form of face-to-face interviews in the initial stage for understanding the sustainable building practice and the problems encountered during their implementation. This survey combined with literature review, and direct observations gave the basis for the formulation of the first research proposition. Whilst this is an appropriate methodology for the interest to understand a current behaviour or practice, a different type of methodology is needed if the objective is to introduce a new practice with the intent of improving an engineering management process, mainly because there is no sample available to take. Therefore, for achieving the main aim of this research there is a need for a type of experiment rather than a survey.

Experimental designs are especially useful in engineering management for addressing evaluation questions about the effectiveness and impact of systems. Emphasizing the use of comparative data as context for interpreting findings, experimental designs increase confidence that observed outcomes are the result of a proposed system or innovation instead of a function of extraneous variables or events. According to Campbell and Stanley (1993), there are two main types of experiments for research: true experiments and quasi-experiments. More recently, some propose that case studies also can be conceived as experiments having similar methodological rules (Campbell and Stanley 1966).

3.2.1 True experiments

This type of experiments requires establishing a control group, that differs in no relevant way from the experimental group (Schutt 2008; Yin 1994). A true experiment was not appropriate for this study because of the difficulty of establishing a control group and lack of control over extraneous variables. At first glance, it would seem to be possible to use a pre-test/post-test measurements of the same group before and after implementation of the system. However, this approach has a main difficulty for use in this research. There are no measurements related to the reliability, production performance and quality proposed in this research are not an explicit, measured objective of traditional planning systems, so pre-test quantitative data is not available.

3.2.2 Quasi-experiments

These are experiments without random assignment to treatment and comparison groups (Campbell and Stanley 1966; Gribbons and Herman 1997). They admittedly sacrifice some of the rigor of true experiments, but are nonetheless appropriate for a large range of inquiry, where true experiments are impossible or inappropriate. The key issue regarding quasi-experiments is what conclusions can be drawn. It is proposed that conclusions are to be justified in terms of study design, the context in which the study occurs, and the pattern of results obtained (Gribbons and Herman 1997). While this strategy responds to the difficulty of generalization posed above, it still leaves us without pre-test quantitative data on workflow reliability, and consequently, is not by itself an adequate strategy for pursuing this research.

3.2.3 Case study

This is a strategy for doing research through empirical investigation of a contemporary phenomenon within its real life context using multiple sources of evidence (Cook and Campbell 1979; Stake 2000). Case studies are an appropriate research strategy when there is little known about the topics of interest, in this case for example, the effect of using Lean Construction principles and Six Sigma methodology in sustainable building projects. A comprehensive case study allows the researcher to pursue a progressive strategy, from exploration of a proposition to more focused examination of trials. Given the nature of the research hypothesis constructed in this study which proposes “the use of Lean Construction principles and Six Sigma methodology for improving the efficiency and effectiveness in the implementation and delivery of sustainable building projects”, a case study strategy seems appropriate.

3.3 Research Methods

3.3.1 Data Collection

Once the research strategy is selected, its execution requires the selection of methods for data collection and analysis. This leads to the identification of methods available especially for case studies, the research strategy to be pursued in this research. From those available, it is important to select the ones that best fit the conditions such as accessibility to people and documents, involvement of the researcher in managerial decision making, time available, etc.

Methods for data collection adopted in this research include direct observation, interviews and questionnaires. To some extent, the researcher acted as a consultant to the project team, therefore, he was in the role of participant observer rather than neutral observer. Interviews were used to collect some relevant and pre-implementation information about the project. Questionnaires helped to collect the views of key members of the project team after the implementation. Documentation and records collected include the project charter, organizational structure, sustainable building assessment and certification documentation and various forms of schedules. Measurements were made and recorded for all assignments, their due dates, actual completion dates, and reasons for failure to complete assignments on their due dates.

3.3.2 Data analysis and evaluation

In relation to data analysis and its evaluation, three main aspects are considered, they are (Yin 1994): reliability, validity, and representativeness. Reliability concerns the extent to which research can be repeated by others with the same results. Validity refers to the problem of whether the data collected is a true picture of what is being studied. Representativeness concerns whether the objects of study are typical of others, and consequently, the extent to which findings could be generalized. In action research, due to the active role that the researcher plays in the generation of the phenomena under study, reliability is inevitably questionable. Validity is especially a problem in survey research because of the possible difference between what people say and what people actually do. However, for action research validity of findings is less a problem because of the availability of measurement data and its public nature.

Representativeness from the case study is a question that cannot be completely answered. Even though, the implementation of the planning system proposed in this research follows a structured methodology with the aim to control key variables, it is recognized that control is partial and incomplete. Unlike laboratory experiments which variables are easier to control, the implementation concerned in this research is made in the messy reality of a construction project.

3.4 Research Process

After the formulation of research propositions and hypothesis, and the research strategy and methods, a research process was designed for systematically conducting efforts in order to achieve the aim and objectives of this study. The research process illustrated in Figure 3.1 mainly contains three phases. The first phase includes literature reviews, interviews and direct observations which helped in the formulation of research propositions and hypothesis. Information obtained in the first phase also provided the basis for the second phase, this is, the development of the proposed planning system (i.e. PLAN-SB) and its implementation framework which is explained in detail in Chapter 4. Action research in the form of a case study is what represents the third phase. The case study not only follows the general structure of action research process but also adopted the DMAIC (Define, Measure, Analysis, Improve and Control) framework proposed by Six Sigma methodology. Third phase is explained in detail in Chapters 5 and 6. Later, results obtained from third phase are used for confirming or disproving propositions and hypothesis formulated in the first phase. Finally, and evaluation survey is conducted for examining in what extent key participants in the case study perceive benefits from the implementation of PLAN-SB.

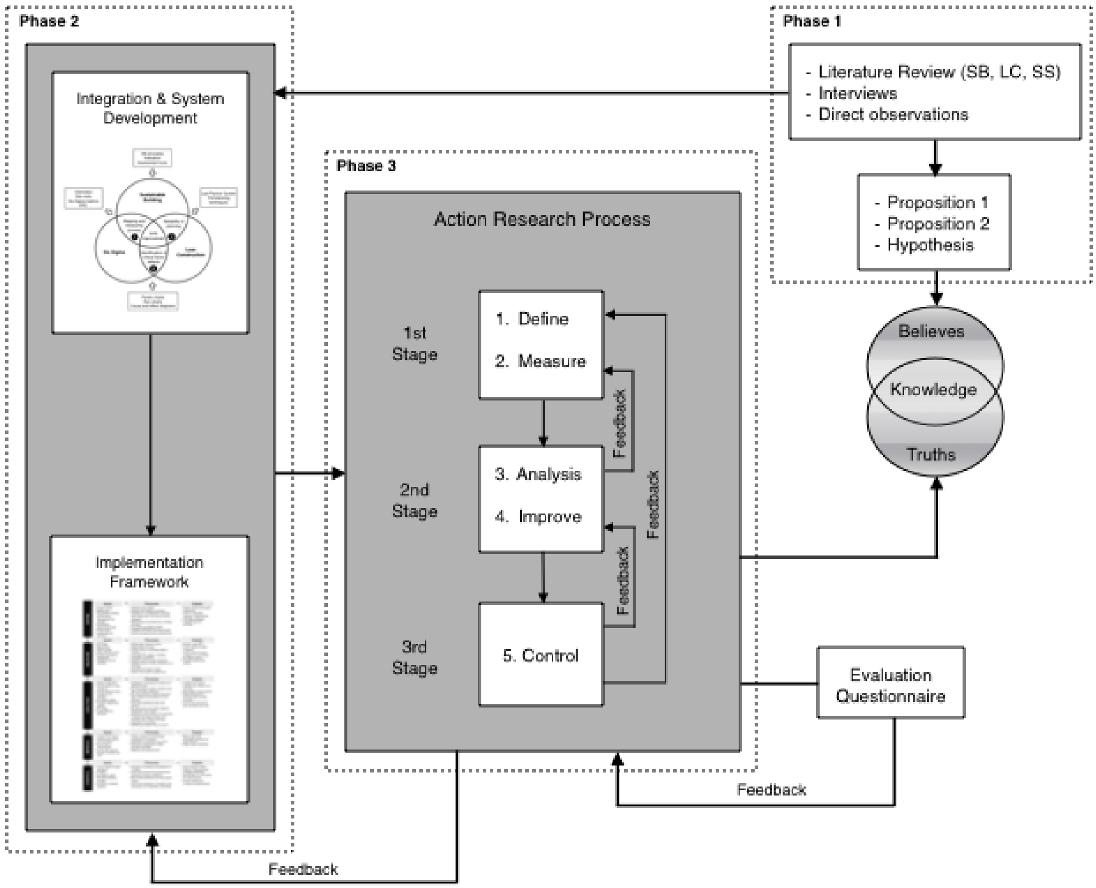

Figure 3.1 Research process

Chapter 4

Development of a production planning system for sustainable building projects (PLAN-SB)

CHAPTER 4: DEVELOPMENT OF A PRODUCTION PLANNING SYSTEM FOR SUSTAINABLE BUILDING PROJECTS (PLAN-SB)

4.1 Introduction

In this chapter, a production planning system for sustainable building projects (PLAN-SB) is to be developed in accordance with the specifications in the Phase 2 of the research process of this study. The chapter presents an integration rationale of Lean Construction and Six Sigma for the purpose of improving the production planning process (PPP) in sustainable building projects. An integration framework is proposed based on three synergies, namely Synergy 1 – Sustainable building and Six Sigma, Synergy 2- Six Sigma and Lean Construction, and Synergy 3 – Lean Construction and Sustainable Building. The synergies present the tools, methods and metrics proposed for the improvement of the PPP. Finally, for the systemic use of the proposed tools, methods and metrics, an implementation framework is developed regarding the steps of DMAIC (Define, Measure, Analysis, Improve, and Control) framework of Six Sigma, which as a whole creates PLAN-SB.

4.2 Integration of Six Sigma and Lean Construction

Even when Lean Construction and Six Sigma have separately brought evident benefits to the construction industry, their applications have limitations. By exploring both their attributes and limitations for the specific purpose of improving the PPP in sustainable buildings projects, the possibility for using them in an integrated way is regarded as the best option. The integration of these two theories is not a new idea. There are examples of integration of Lean and Six Sigma principles mostly in manufacturing industry (Fellows and Liu 2003) and some few cases in the construction industry (George 2003). In fact, Abdelhamid (2003) stated that Lean Construction has significant synergy with Six Sigma, and argued that both place considerable emphases on identifying what customer values in services and products and help to improve processes to better deliver them. Based on the previous attempts of integration, this study extends the boundaries of integration and applies it for meeting the aims of improvement of the PPP for helping in the delivery process of sustainable buildings during the construction stage.

Integration Rationale

As previously mentioned, a good PPP must be able to efficiently and effectively generate schedules that reflect the actual constraints and objectives of the construction environment, and allow the reduction of workflow variability. This is an important issue in the construction industry due to the fact that variability in the workflow often prolongs cycle times and decreases system throughput by increasing the amount of waste in a process (Abdelhamid 2003; Hopp and Spearman 1996). In this sense, it is found that Lean Construction can help to optimize the PPP by identifying and eliminating activities that do not add value. However, Lean Construction does not help to define what a defect is in the process and therefore quality is very difficult to be determined. If defects cannot be defined and measured, quantitative goals for reducing workflow variability cannot be established. Thus, Lean Construction is able to optimize PPP, but do not help to eliminate or reduce variability by removing the root causes of the whole. On the other hand, Six Sigma is developed with focusing on reducing variations (defects) as a way to improve processes. However, Six Sigma does not address the way process flow is to be optimized. Therefore, Lean Construction and Six Sigma complement each other when used together. They represent a powerful framework for developing a production planning system that considers value (sustainability), optimize the process and reduces variability. Based on the above rationale, the development of a production planning system for sustainable building projects (PLAN-SB) is pursued, which presents an integration framework between Lean Construction and Six Sigma, as shown graphically in Figure 4.1.

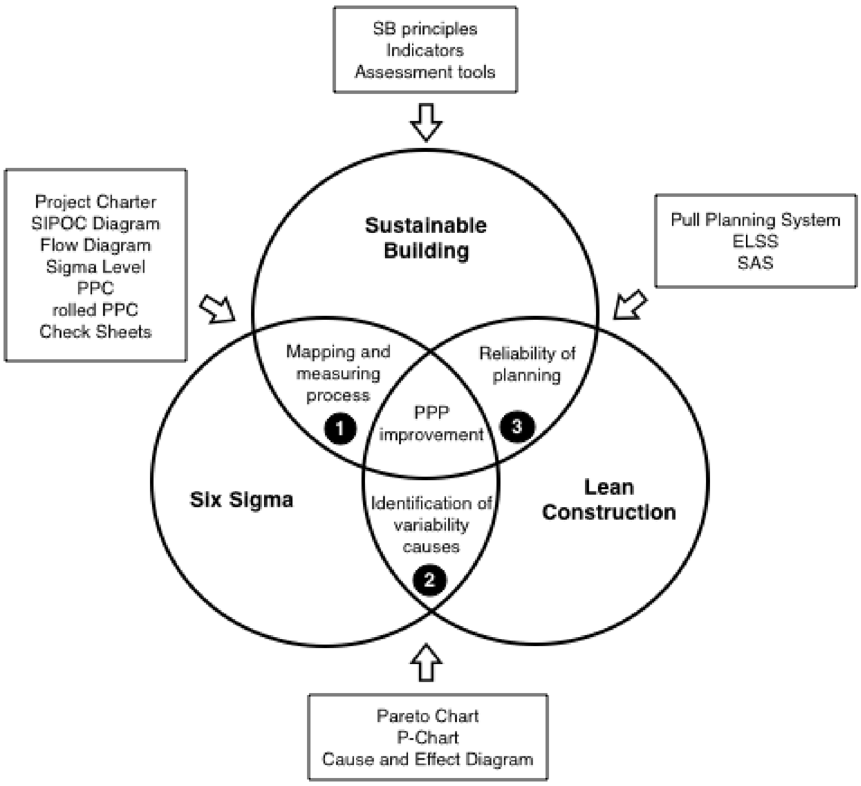

Figure 4.1 Lean Construction and Six Sigma Integration framework

4.3 PLAN-SB Development

PLAN-SB is a production planning system developed from the integration of Lean Construction principles and Six Sigma methodology which aims to improve the efficiency and effectiveness of the PPP in the implementation and delivery of sustainable building projects. In this section, the explanation of the synergies of the three main elements (i.e. Sustainable Building, Lean Construction and Six Sigma) is presented. The selection of tools, methods and metrics and their systematic application are proposed regarding the steps established in DMAIC framework (see section 2.4.3) which as a whole creates PLAN-SB.

Sustainable building

As appreciated in Figure 4.1, 'Sustainable Building' represents one of the main elements of this integration framework. If the intention is to propose a system for improving the PPP to help to implement and deliver them, it is essential to understand what defines them. In order to define a sustainable building and what determines its sustainability performance, the identification of its principles, indicators and assessment methods is necessary. This identification information will help to classify those activities that are related to sustainable deliverables, which as a whole define the sustainability performance of a whole building. For the purposes of this research, these activities are denominated as "G activities". The importance related to the identification of "G activities" lies on the aim to differentiate their performance against "O activities" ("O activities" are defined as those with no direct relation with sustainable deliverables). The classification of the two types of activities can lead to a better understanding of the different causes affecting sustainability performances and the management needs related to them.

Numerous indicators and assessment tools have been developed in the process of achieving higher sustainability performance in buildings and these are used to monitor specific aspects such as energy and water use. Several literatures provide valuable references of these indicators; these include BEES (Tommelein 2000), Simapro (NIST 2007), EcoQuantum (PEC 2009), LCExplorer (Kortman et al. 1998), DOE2 (Norris 2002). However, these indicators are considered too specific for classifying the varied and numerous activities in a sustainable building project. More general indicators are needed which can help to relate day-to-day programmed activities with sustainable deliverables. Sustainable building assessment and certification systems such as BREEAM, GBTool, BEAM and LEED contain the suitable indicators that assist to define the desire objectives and strict performance criteria of an entire building. Particularly, the indicators and benchmarks contained in these systems have contributed enormously in the promotion of sustainable building projects. They help to define sustainability performance levels and to ensure that evidence of sustainability can be obtained in the assessment process (BEER 2000; Cole 2005). Each indicator owns a certain number of credits and these are awarded according to the level of compliancy with the benchmarks related to them. Indicators are selected and credits allocated depending on national, regional or local contexts and conditions (Howard 2005). Therefore, the indicators and benchmarks contained in these tools are considered an appropriate reference for classifying “G activities”. However, it is recognized that a great variety of sustainable building assessment and certification systems currently exist in practice. Therefore, the decision of which assessment framework and indicators to be selected for classifying “G activities” will depend on the location of the project and/or on the project adopted for certifying the sustainability performance of the building.

4.4 Synergy 1 - Sustainable Building and Six Sigma

4.4.1 Mapping process

In the process of defining and improving the PPP in sustainable building projects it is important to acknowledge the difficulty from one project to another, which demonstrates the need to define the PPP for each case to be studied. In this attempt, it is appropriate to use mapping process techniques in the methodology of Six Sigma that can assist to describe the PPP. The underlying principles of process mapping involve determining the process inputs and outputs, flow of information and all cross-functional activities (Damelio 1996; ISO 2004). Once these are determined, it is easier to create a process map. For the purpose to map the PPP, two different techniques are adopted namely SIPOC (Supplier, Input, Process, Output, and Customer) Diagrams and Flow Diagrams.

SIPOC Diagram

SIPOC is a high level map of a process to view how customer requirements are satisfied (Pojasek 2004; Rasmusson 2006). SIPOC stands for: Supplier, Input, Process, Output and Customer. A SIPOC diagram is proposed to be applied in the 'Define' stage of DMAIC. Definition of quality and identification of value in the PPP is an important process for its improvement, therefore, SIPOC is used for judging quality and value based on the output of the process and PPP improvement by analyzing inputs and process variables.

Flow Diagram

A flow diagram is a visual representation of all major steps in a process. It helps to understand a process better by identifying the actual flow or sequence of events in a process (Basu 2009; Pyzdek 2003). A flow diagram of the PPP is proposed to allow coming to a consensus regarding the steps of the process and to identify critical and problematical areas for improvement.

By using these techniques to map PPP, the following advantages can be obtained:

- Give a clear big picture of the process
- Define the key inputs and outputs
- Facilitate the understanding of cross-functional activities
- Show the interface between various contributors in the process
- Show how the process flows through the organization

For accurately mapping a process, it is important to obtain related information that can help to truly represent it. Therefore, two approaches for obtaining information are adopted: interviews and observations. Interviews with key project team members across the PPP from inputs to outputs will generate information to help producing a first draft of the PPP map. Direct observations help to develop a more detailed PPP map and its validation is obtained from the project team members in close familiarity to the PPP. Mapping the PPP is a crucial step and its closeness with the real process is of vital importance since the analyses and proposed improvements are based on the information contained in the map.

Project Charter

A project charter is a working document for defining the terms of reference for a specific project (Basu 2009). The charter is an important mechanism to project management by specifying necessary resources and boundaries that will in turn ensure success (Snee and Hoerl 2003). A project charter is considered as a starting point in the implementation of PLAN-SB and it takes place in the Define stage of DMAIC. Information contained in the project charter includes: project title, project type, project description, project purpose, project scope, project objectives, project team and timing. Generally, a project charter is used in Six Sigma methodology for defining an implementation project. In this study, an implementation PLAN-SB project charter is used for enabling and enhancing the possibilities of successfully achieving the following stages in DMAIC framework.

4.4.2 Measurement process

Once the PPP is represented in a map for better understanding and communicating the PPP, of equal importance is to measure its performance, which is used as reference for setting improvement goals. In this sense, two metrics are borrowed from Six Sigma and Lean Construction, namely 'Sigma Level' and 'Percent Plan Complete (PPC)' as introduced in Sections 2.4.4 and 2.3.5. Sigma Level advantages are related to the ability to provide a detailed understanding of the process and accurately communicate its performance (Basu 2009). Moreover, Sigma Level normalizes the representation of the performance measurement which allows to compare it against various activities and processes (Breyfogle 2003), a very useful faculty when comparing the performance of 'G activities' with 'O activities'.

The metric known as PPC is proposed in the previously introduced Last Planner System in Section 2.3.3. This metric is represented as a percentage with a range from 0% to 100% and is calculated as a ratio of the number of activities completed to the total number of activities planned in a given period of time. Therefore, the higher the PPC, the more reliable the PPP is. Six Sigma metric 'Yield' (Y) represents the percentage of the units that pass final inspection without defects relative to the number of units that were processed (Warren 2004). Therefore, if defects are considered as the activities that were not completed in due date as specified in the production plans (weekly work plans), PPC can be used to represent the same function as Y. Six Sigma also uses a metric called 'rolled throughput yield (Y_{RT})', which communicates the probability that a single unit can pass through a series of process steps free of defects (Bass 2007). Y_{RT} exposes the hidden factory (rework performed to rectify defects during sub-processes) and provides a better sense of magnitude of the process performance failure (Breyfogle and Cupello 2001). Abdelhamid (2003) suggested the use of this metric for exposing the hidden factory in manufactured homes factories and as suggested in this study, he used PPC as Y metric for calculating Y_{RT} which named it 'rolled PPC'. While Y_{RT} or 'rolled PPC' could be regarded as a very strict performance metric for the nature of the construction industry, its adoption is considered effective in order to measure improvement from day-to-day performances and to expose the deficiencies in sub-processes involved in the delivery of sustainable building projects.

How to calculate rolled PPC?

The Y_{RT} can be mathematically shown as follows:

$$Y_{RT} = \prod_{i=1}^{m} Yi \quad (1)$$

Where (m) is the number of sub-processes involved and (Y_i) is the throughput yield of process *i*.

In applying the principles of function (1), the modified equation proposed for this research using PPC is as follows:

- The rolled PPC is calculated using PPC values of each sub-process (PPC*i*) as follows:

$$rolled\ PPC = \prod_{i=1}^{m} PPC_i \quad (2)$$

How to calculate Sigma Level?

The Six Sigma Levels are obtained by converting the Y_{RT} to a Sigma Level so that comparison is possible across different operations and even across industries. This can be achieved by using standard tables or by calculations. The Sigma Level for a process using Y_{RT} can be calculated using the following set of equations (see Breyfogle (2003) for more discussion):

- The rolled throughput yield (Y_{RT}) is calculated by using equation (1):

  i.e. $Y_{RT} = \prod_{i=1}^{m} Yi$

- Typically, yields for each of the (m) steps within a process differ. Rolled throughput yield (Y_{RT}) gives an overall yield for the process and a normalized yield value (Y_{norm}) for the process steps is obtained as follows:

  $Y_{norm} = \sqrt[m]{Y_{RT}}$ ……………………………………………………(3)

- The normalized (Y_{RT}) is then converted to Defects Per Unit (DPU) using the following equation:

  $DPU_{norm} = -\ln(Y_{norm})$ ………………………………………………(4)

- To determine the Sigma Level, for the process the following function is used

$$Sigma\ Level = Z_{norm} + 1.5 \tag{5}$$

Where, Z_{norm} is the standard normal value corresponding to the DPU_{norm} found using the standard normal table.

The calculation of Sigma Level for the PPP

In order to calculate the Sigma Level of the PPP, rolled PPC from function (2) is used as Y_{RT} metric. Thus, in applying the principles of functions (3), (4) and (5) the modified equation proposed for this research using rolled PPC are as follows:

- The rolled PPC is normalized by finding the geometric mean as follows:

$$PPC_{norm} = \sqrt[m]{rolled\ PPC} \tag{6}$$

- The normalized PPC is then converted to Defects Per Unit (DPU) using the following equation:

$$DPU_{norm} = -\ln(PPC_{norm}) \tag{7}$$

- To determine the Sigma Level for the PPP, equation (5) is used:

i.e. $$Sigma\ Level = Z_{norm} + 1.5$$

Where, Z_{norm} is the standard normal value corresponding to the DPU_{norm} found using the standard normal table.

The Sigma Level corresponds to 'parts per million' (ppm) which essentially is the number of defects per million parts. Hence, this metric emphasizes the magnitude of the problem. It gives a more representative picture of the state of the process. A low Sigma Level indicates need for process analysis and improvement.

Moreover, experience has shown that processes usually do not perform as well in the long-term as they do in the short-term, as a result the number of sigmas that will fit between the process mean and the nearest specification unit may well drop overtime compared to an initial short term study (i.e. a process that is operating at 6 sigma in the short-term will only operate at 4.5 sigma in the long-term). To account for this real-life increase in process variation overtime an empirical-base 1.5 Sigma shift is introduced in the calculation (Breyfogle, 2003).

There is no specific timeframe to indicate what is short-term and long-term, it varies from process to process. For instance, if special causes of variation in a process are presented once a month, then one month can be considered as short-term

Check Sheets

The check sheets are a simple and convenient recording method for collecting and determining the occurrence of events. These sheets or forms allow to systematically record or compile data from observations so that trends can be shown clearly (Breyfogle 2003; George et al. 2005). The check sheets are very easy to apply and are used in PLAN-SB to record the ‘completion’ or ‘non-completion’ of activities in due time by comparing what specified in the production plans and the reasons for non-completion (Reasons-NC). The check sheet designed for PLAN-SB is presented in Table 4.1. The sheets are prepared in advance for each workable day in the project and site supervisors are responsible for recording the data. There are multiple advantages of using check sheets. The adoption can improve record efficiency as a tool for data collection, it makes patterns in the data clear and allows for the PPP analysis be based on facts. Reason for non-completion (Reason-NC) is important information to be recorded for each single activity. These reasons will be compared to a generic list containing a classification of these reasons which is prepared based on previous studies found in the literature (Alarcon et al. 2005; Ballard 1999; Ballard 2000; Basu 2009; Botero and Alvarez 2005) (See Table 4.2). Consequently, Reasons-NC contained in this table need to be modified according to the context and needs of the project in study and validated by the project team.

Table 4.1 PPC and reasons for non-completion check sheets

Percent Plan Complete (Daily Compilation)								
	Day: Week: Date:							
				% Completed		Acomplished		
Activity Number	Activity Description	Total Duration (days)	Activity day	Planned	Real	YES	NO	Reasons for noncompletion
Observations:								

Table 4.2 Reasons for Non-completion

Reason-NC (ID)	Reasons for non-completion
1	Waiting for materials from warehouse
2	Waiting for materials from supplier
3	Waiting for workers/tools/equipment
4	Lack of access
5	Equipment breakdowns
6	Changes/redoing work (design errors)
7	Changes/redoing work (site errors)
8	Moves to other work area (priority change)
9	Waiting for information
10	Lack of continuity (prerequisite work not completed)
11	Overcrowded working areas
12	Inclement weather
13	Other

4.5 Synergy 2 - Six Sigma and Lean Construction

4.5.1 Identification of variability causes

Once a process performance is measured, it allows to identify where poor performance is located and simplifies the detection and analysis of its causes. Then, causes affecting the performance should be rectified or removed for enabling the process improvement.

For the detection of causes affecting the performance of a process, Pande (2005) proposed that the best way to do it is presenting these causes with visual tools. Visual presentation of information helps to better understand the process and to identify the source of the problem. Some common techniques used for visual presentation are: Pareto Charts, Frequency Plots, Run Charts, Control Charts, Cause and Effect Diagrams, and Correlation Diagram (Evans and and Lindsay 2001; Pande et al. 2000). The Pareto Charts used in Lean Construction and Control Charts and Cause and Effect Diagrams used in Six Sigma are adopted in PLAN-SB in this study for the identification and analysis of the critical factors affecting the PPP performance. Their principles and reasons for adoption are explained in the following sections.

Pareto Chart

A Pareto Chart is a special form of bar chart that rank orders the bars from highest to lowest for prioritizing problems of any nature (Ruffa 2008). It is know as ‘Pareto’ after a nineteenth century Italian economist Wilfredo Pareto who observed that 80% of the effects are caused by 20% of the causes: the ‘80/20 rule’ (Pande et al. 2000). Pareto Charts are considered a useful tool in optimizing efforts and they are easy to understand and apply. PLAN-SB adopts Pareto Charts in the Analysis step of DMAIC to determine the priorities of problems in order to allow improvement efforts to be directed to those priority areas that will have the greatest impact. An example of a Pareto Chart is shown in Figure 4.2.

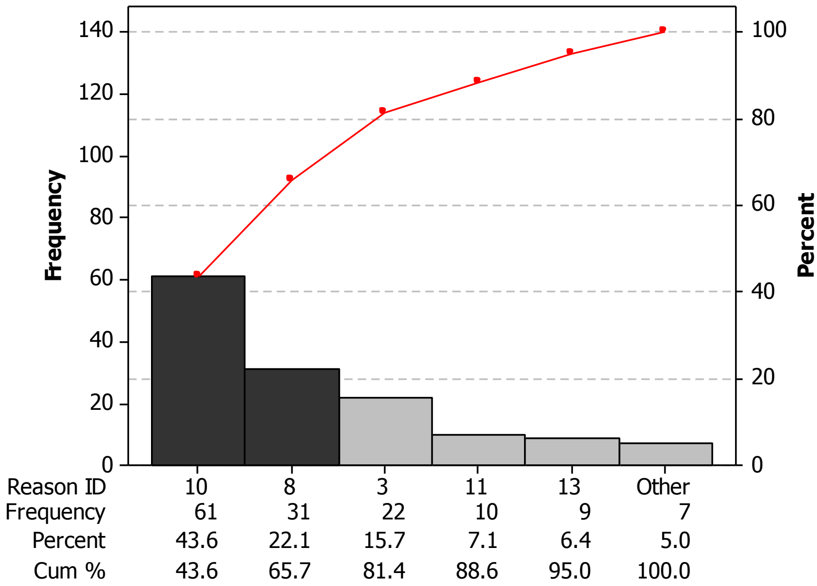

Figure 4.2 Pareto Chart

Control Chart

While Pareto Charts help to identify critical causes by its frequency in a period of time, Control Charts help to identify the relation between causes generating critical variation patterns over time. A Control Chart consists of a graph with time on the horizontal axis and an individual measurement (such as PPC) on the vertical axis as shown in Figure 4.3. Control Charts are useful for determining whether a process is stable and also for distinguishing common causes of variability from special causes (George et al. 2005; Joiner Associates 1995b). PLAN-SB proposed in this research adopts Control Charts for understanding the PPP performance, analyzing the behavior of its variations and how these are responding to a change or attempts for improvement. A variety of Control Charts exists which are widely applied in different industries for monitoring processes. However, not all Control Charts are suitable for PLAN-SB since in construction projects the number of activities (i.e. products or samples) is variable over time. Therefore, P-Charts tool is proposed for application. P-Charts is the only type of Control Charts that allow the variability in sample size, therefore, it is the most adequate for PLAN-SB. An example of a P-Chart is illustrated in Figure 4.3.

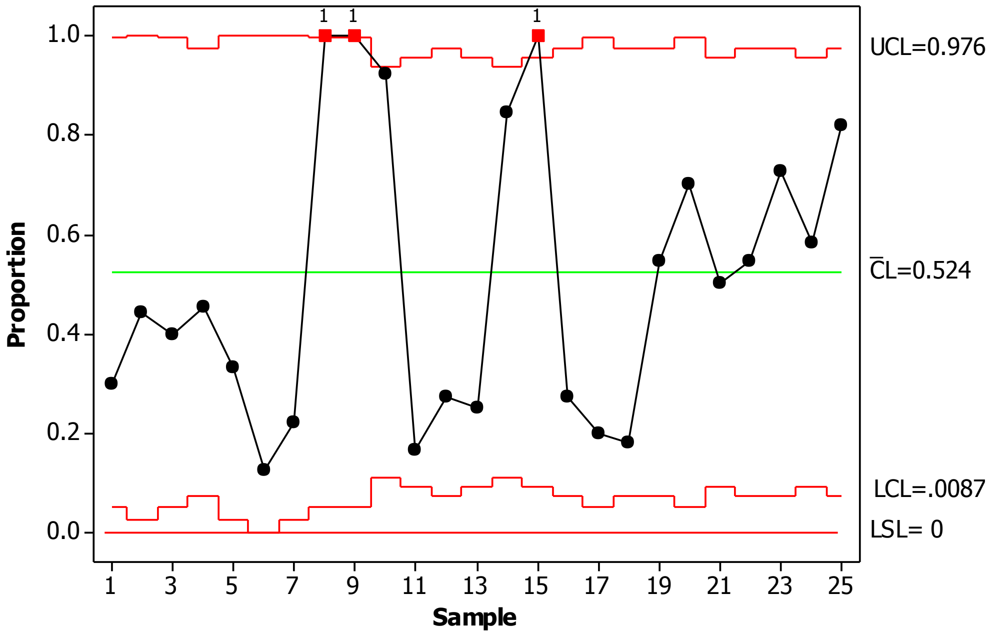

Figure 4.3 P-Chart

In P-Charts, three control limits are drawn: the central line (CL), the lower control limit (LCL) and the upper control limit (UCL) (Breyfogle 2003). Values above the UCL or below the LCL indicate special cause of variation called signals. If no signals occur the process is assumed to be under control, (i.e. only common causes of variation are present). For the purpose to identify the special reasons for non-completion of activities in due time, the PPC metric is used to draw the P-

Chart, but for facilitating the analysis, PPC metric is converted to a Percent Plan Incomplete (PPIC) metric, which is calculated as 1-PPC or as a ratio of tasks incomplete to the tasks planned. And, the CL and limits (LCL and UCL) for each period of time can be calculated using the following formulas (adapted from Breyfogle (2005)):

$$PPICavg = \frac{\Sigma\ Tasks\ incomplete}{\Sigma\ Tasks\ assigned} \tag{10}$$

$$UCL = PPICavg + 3\sqrt{\frac{PPICavg\ (1\text{-}PPICavg)}{\Sigma\ Tasks\ assigned}} \tag{11}$$

$$CL = PPICavg \tag{12}$$

$$LCL = PPICavg - 3\sqrt{\frac{PPICavg\ (1\text{-}PPICavg)}{\Sigma\ Tasks\ assigned}} \tag{13}$$

UCL and LCL can either be mathematically calculated as explained above or set by the goals of the project. Since the aim of PLAN-SB is to maintain a performance as near as 0% PPIC. Therefore, LCL is set up and changes to Lower Specification Limit (LSL) of 0%. On the other hand, UCL can either be calculated based on statistical PPIC registered or be defined as a goal (e.g. PPIC greater than 70% is consider out of control). Besides the analysis of special causes which are out of control, a series of test are adopted based on the behavior of the data through the P-Chart. These tests help to better understand the changes in performance and the positive and negative trends of PPIC over time. Accordingly, PLAN-SB will adopt 4 types of tests as proposed in Six Sigma methodology (Breyfogle 2003):

Test #1 - 1 PPIC value > 3 standard deviations from the center line

Test #2 - 9 consecutive PPIC values on same side of Center Line (CL)

Test #3 - 6 consecutive PPIC values, all increasing or all decreasing

Test #4 - 4 consecutive PPIC values, alternating up and down

Cause and Effect Diagrams

P-Charts are useful for determining how stable a process is and for distinguishing usual causes of variability from unusual causes. However, nothing will change just because they are chartered. Something should be done to identify their root causes and implement something to eliminate them. The Cause and Effect Diagram is adopted for the purpose. Cause and Effect Diagram is a graphical representation of potential causes for a given effect (Breyfogle 2003; Joiner Associates 1995a). The purpose of the diagram is to assist in enabling a team to identify and graphically display, in increase detail, the root causes of a problem through brainstorming sessions. Since the technique was first introduced by Ishikawa, this type of illustration is also known as an Ishikawa diagram. In addition, it is often referred to as a 'fishbone' diagram due to its skeletal appearance. The Cause and Effect Diagram is arguably the most commonly used of all quality improvement tools. The 'Effect' is a specific problem and is considered to constitute the head of the diagram. The potential causes and sub-causes of the problem form the bone structure of the skeletal fish. By adopting Cause and Effect diagrams in PLAN-SB the efforts for eliminating reasons for non-completion of activities will consider both its root causes rather and its symptoms. For effectively applying the tool an example of a Cause and Effect Diagram is illustrated in Figure 4.4.

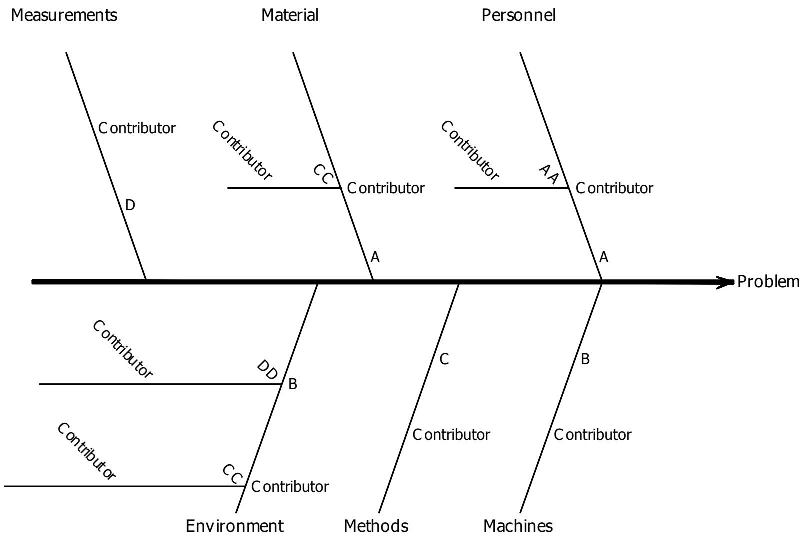

Figure 4.4 Cause and Effect Diagram

According to Basu (2003) there are 5 major steps to follow for building the diagram and identifying the possible root causes of the problem:

Step 1 – Identify and clearly define the problem/effect to be analyzed.

Step 2 – Identify the main causes contributing to the problem/effect being studied. These are the labels for the major branches of the diagram and become categories under which to list causes related to those categories.

Step 3 – For each major category, identify other specific factors which may be the causes of the problem/effect.

Step 4 – Identify increasingly more detailed levels of causes and continue organizing them under related causes categories.

Step 5 – Analyze the diagram.

4.6 Synergy 3 – Lean Construction and Sustainable Building

4.6.1 Reliability of planning

The tools and metrics introduced in the previous two synergies in Sections 4.4 and 4.5 are adopted in PLAN-SB to better understand the PPP and therefore determine which are the potential options for its improvement. In specific, the unusual reasons for non-completion of assignments and its root causes are an excellent indicator of where improvement should be attempted. By eliminating these causes, important and crucial improvement could be achieved, namely by increasing PPP's reliability. If PPP's reliability is increased, the variability in the workflow is reduced and all negative consequences related to the variability shall be eliminated (the symptoms). The elimination of reasons for non-completion of activities is proposed by changing from a traditional 'Push Planning System' to a 'Pull Planning System' which have been discussed in section 2.3.3. This change implies the analysis and screening of all activities for eliminating all possible constraints that could affect their successful completion in due time before these activities are actually included in the production plan.

As discussed in Section 2.3.3, a successful exponent of a Pull Planning System applied in construction is the Last Planner System. The Last Planner System presents a Lookahead planning model where activities are subjected to a constraint analysis to make sure they are ready to be executed. Activities that are made ready for execution enter into a backlog and these can be programmed in the production plans. PLAN-SB adopts the Lookahead planning model for making activities free of constraints before they are actually programmed in order to enhance the PPP’s reliability. PLAN-SB in this research proposes two main tools for implementing the Lookahead planning model, these are: the ‘Engineering Lookahead Schedule Sheet (ELSS)’ and the ‘Screening Activity Sheet (SAS)’.

Generally, any construction project will hold ‘General Coordination Meetings’ in regular basis with concerned project team members. For example, these could be every week or every two weeks according to the needs of the project team. In these meetings among several issues the main points of the agenda are occupied by discussions regarding, for example, the progress of the project, milestones to be met, special permitting issues, site logistics, problems arising causing delays or quality defects, and the plan for coming activities. ELSS and SAS are designed for their use in these meetings. It is precisely to present the ELSS and SAS in these meetings where activity constraints are discussed and production plans approved in consensus of the main team members involved. The goal of ELSS and SAS is to make the ‘General Coordination Meetings’ more efficient by judiciously disseminating the necessary and only relevant information to those participants that need it. These tools will enable the participants to identify potential conflicts ahead of time. Affected participants can study the identified problems, obtain more information if needed before the discussion on the meeting, and then spend the meeting time constructively solving coordination problems, rather than detecting them or generating creative alternatives. Even when there are no conflicts, participants can use their shared plans to better understand how, when, where and with whom they are going to coordinate the use of shared resources.

Engineering Lookahead Schedule Sheet (ELSS)

ELSS is a tool that facilitates the analysis of future activities to be programmed in production plans. ELSS is prepared based on the milestones included in the 'Master Schedule' and the progress reports. Four weeks from the 'Master Schedule' are exploded to the level of activity and described in detail the number of days necessary for their completion or expected progress. ELSS should be ready for distribution at least one week in advance from the 'Week 1' to be analyzed. ELSS is considered a source of valuable information since it includes the expected progress during 4 weeks according to the latest progress reports and milestones to be met with enough time ahead to be analyzed. ELSS is shown in Table 4.3.

Table 4.3 Engineering Lookahead Schedule Sheet (ELSS)

Engineering Lookahead Schedule Sheet (ELSS)

Planner:
Checked by:
Meeting Date:

Activity	Week 1						Week 2						Week 3						Week 4						Outstanding Needs
	June						June						July						July						
	16	17	18	19	20	22	23	24	25	26	27	29	30	1	2	3	4	6	7	8	9	10	11	13	
	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	M	
Activity A	■	■	■	■	■																				
Activity B	■	■	■	■	■																				
Activity C						■	■	■	■	■	■														
Activity D												■	■		■	■	■	■	■	■	■	■	■	■	
Activity E												■	■		■	■	■	■	■	■	■				
Activity F																						■	■	■	
Activity G	■	■	■	■	■																				
Activity H																						■	■	■	
Activity I																		■	■	■	■				
Activity J						■	■	■	■	■	■														
Activity K		■		■		■		■																	
Activity L	■	■	■	■	■																				
Activity M		■																							
Activity N	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■		■	
Activity O		■	■	■	■			■	■	■	■				■	■	■	■			■	■	■	■	
Activity P	■		■	■																					
Activity Q	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Activity R	■	■	■	■	■																				
Activity S	■																								

Screening Activity Sheet (SAS)

The SAS works as a complementary tool for ELSS, and these two are simultaneously prepared for the analysis of the same activities and same period of time. The main function of SAS is to provide the function to screen all activities in the aim to eliminate their constraints. Different types of activities have different constraints. In this sense, SAS defines its screening constraints by performing an analysis of root causes related to the Reasons-NC with high frequency and causing critical variation in the workflow. Screening constraints should be generated from the data recorded in the project under analysis since these represent particular areas of the project for potential improvement. SAS is shown in Table 4.4.

Table 4.4 Screening Activity Sheet (SAS)

Screening Activity Sheet (SAS)										
Meeting Date:										
Period:										
Activity	Responsible Party	Contract/ change order	Design	Materials	Labor	Equipment	Prerequisite work	Submittals	Transportation	Space
Activity A										
Activity B										
Activity C										
Activity D										
Activity E										
Activity F										
Activity G										
Activity H										
Activity I										
Activity J										
Activity K										
Activity L										
Activity M										
Activity N										
Activity O										
Activity P										
Activity Q										
Activity R										
Activity S										

4.7 PLAN-SB Implementation Framework

In previous sections, the rationale for integration and selection of methods, tools and metrics have been addressed for developing PLAN-SB. However, in order to follow a sequenced implementation of PLAN-SB an implementation framework is developed based on the generic framework DMAIC (Define, Measure, Analyze, Improve, and Control) and IPO (Input, Process and Output) Diagram as shown in Figure 4.5. DMAIC is one of Six Sigma implementation frameworks, as discussed in Section 2.4.3, and is used in PLAN-SB to give a sequenced implementation process and a clear understanding of the purposes and goals to be achieved in each step of PLAN-SB implementation. On the other hand, IPO is used to define each of the steps of PLAN-SB and demonstrate the relationships between input and output elements. The implementation framework for PLAN-SB is presented in Figure 4.5. The application and effectiveness of the framework will be investigated in following Chapters.

Phase	Inputs	Processes	Outputs
DEFINE	• Project charter • Master schedule • Sustainable building assessment and certification system • Implementation project team • Organizational structure	• Identify project goals • Identify, classify and validate G activities • Interviews • Direct Observations • Document PPP • Develop PPP's SIPOC Diagram • Develop PPP's Flow Diagram • Validate SIPOC and Flow Diagram • Analysis of PPP's diagrams looking for potential areas for improvement	• Implementation project charter • List of measurable customer requirements • G and O activities classification • PPP's SIPOC Diagram • PPP's Flow Diagram • Potential areas for improvement
MEASURE	• PPP's SIPOC Diagram • PPP's Flow Diagram • Master schedule • Production plans • PPC and reasons for non-completion check sheets • Potential areas for improvement • G and O activities classification	• Define data collection plans • Observations on-site • Define status of activities • Identify reasons for non-completion • Calculate PPC • Calculate rolled PPC • Calculate Sigma Level	• PPC values • rolled PPC values • Sigma Values • Reasons for non-completion • In-depth understanding of Potential areas for improvement refined
ANALYSIS	• PPC values • rolled PPC values • Sigma values • Reasons for non-completion • Potential areas for improvement • PPP's SIPOC Diagram • PPP's Flow Diagram • Organizational structure • Master schedule • Implementation project charter • G and O activities classification	• Categorize reasons for non-completion • Identification of critical areas for improvement (Pareto Charts) • Identify important plan variations and unusual causes (P-charts) • Generate hypothesis about the causes • Identify the root causes (Cause and effect diagram) • Compare G and O activities performances and causes • Identify and prioritize opportunities for improvement • Define constraints to be used in SAS	• Root causes for G and O activities • Prioritized opportunities for improvement • Comparative analysis of G and O activities • Constraints to be used in SAS
IMPROVE	• Root causes for G and O activities • Prioritized opportunities for improvement • Comparative analysis of G and O activities • Constraint to be used in SAS • Engineering Lookahead Schedule Sheet (ELSS) • Screening Activity Sheet (SAS) • Master schedule • PPC and reasons for non-completion check sheets	• Modify PPP • Implement Lookahead planning • Implement Screening constraint analysis • Eliminate constraints from activities • Observations on-site • Define status of activities • Identify reasons for non-completion • Calculate PPC • Calculate rolled PPC • Calculate Sigma values • Document and verify improvements	• PPC values • rolled PPC values • Sigma Values • Reasons for non-completion • Quantified improvement achieved
CONTROL	• Quantified improvement achieved • PPC values • rolled PPC values • Sigma Values • Reasons for non-completion • Engineering Lookahead Schedule Sheet (ELSS) • Screening Activity Sheet (SAS) • Master schedule • PPC and reasons for non-completion check sheets	• Observations on-site • Define status of activities • Identify reasons for non-completion • Calculate PPC • Calculate rolled PPC • Calculate Sigma values • Document and verify improvements • Analysis of variations and patterns in P-charts • Document and verify sustained improvement • Compare before/after Improve stage	• Improvement verified • Failure of improvement identified • Identification of new areas for improvement • Ensure lasting and continuous improvement

Figure 4.5 PLAN-SB Implementation framework

Chapter 5

Implementation of PLAN-SB

CHAPTER 5: IMPLEMENTATION OF PLAN-SB

This Chapter presents the implementation of the system PLAN-SB by following the system principles and implementation framework presented in Chapter 4 to a particular project. It follows the general structure of the action research method as shown in the Phase 3 of the Research Process designed for this study. And, Phase 3 of this thesis is divided into three main stages for implementing PLAN-SB, they are:

- First Stage (Define and Measure),
- Second Stage (Analysis and Improve) and,
- Third Stage (Control).

5.1 First Stage (Define and Measure)

The implementation framework of PLAN-SB was developed in Chapter 4 based on the generic framework DMAIC (Define, Measure, Analyze, Improve, and Control) from Six Sigma methodology. The first two steps (i.e. Define and Measure) have the common purpose of providing with precise information about the process to be improved and identify potential areas for improvement. This information is later used for analyzing and improving the process. The types of information needed in order to lead to the selection of the best strategies for the improvement of the Production Planning Process (PPP) have been well defined in Chapter 4. This information is to be acquired in the First Stage of the PLAN-SB by means of the Define and Measure steps. Nevertheless, the two steps have each specific information targets and the way the information is obtained, these are to be presented in the following two sections.

5.1.1 Define step

The Define step particularly targets the collection of information including the general background of the case under study, and more precise information that helps to build the Organizational Structure Chart, the SIPOC Diagram, the Process Flow Diagram and the Project Charter. The collection of the Define step information will help identify potential areas for improvement.

5.1.1.1 General background of case study

For the implementation of PLAN-SB, the first meeting was held with the Chief Executive Officer (CEO) of Contractor X[1] in which a 15 minutes presentation was delivered for briefly introducing PLAN-SB and the expected benefits of its implementation. The idea was well taken and a second meeting was arranged with the Senior Project Manager of Project SB-T2[1] who is also member of the Committee for Innovation within Contractor X. In the second meeting (on the construction site), the Project SB-T2 was introduced to the researcher and PLAN-SB was also introduced in more detail to the Senior Project Manager, Planning Manager and two Assistant Building Engineers. The decision for implementing PLAN-SB was then taken.

Contractor X

Contractor X is a leading construction company in Southeast Asia and has been building a wide range of construction projects for over 50 years. It has an annual turnover of more than US$ 1 billion and employs 3,000 full-time staff. By the

[1] For confidentiality purposes, the names of the contractor, personnel and project need to be altered. The contractor is named as Contractor "X", the project as Project SB-T2 and the personnel is referred by the name of their position within the organizational structure.

time this study was carried out Contractor X was executing 18 building projects and 5 of them are pursuing sustainable building certifications. This company has previously delivered 4 sustainable buildings with HK-BEAM certification in Hong Kong.

Project SB-T2

The Project SB-T2 is a residential development in Hong Kong. Project SB-T2 consists of two residential towers with 69 floors each and a total of 275 flats. The Construction Floor Area (CFA) is 47,308 m2 and the contract sum reached HKD$ 644M. There is one main contractor (i.e. Contractor X) and 18 different sub-contractors, nearly all works are subcontracted except for some preliminary works (setting out, cleaning, electricity). 'HK-BEAM 4/04 for New Buildings' is the sustainable building assessment and certification system adopted in this project and its highest sustainability level certification was achieved (i.e. Platinum).

5.1.1.2 Organizational Structure Chart

The organizational structure chart of the Project Team is important information to be obtained in the Define step. The organizational structure helps to understand project team members' roles and to identify those ones with direct participation in the elaboration of the production plans. However, the organizational structure chart of Project SB-T2 was originally too general and incomplete for identifying all project team members. Therefore, one Assistant Building Engineer and the Researcher drafted a more comprehensive organizational structure chart for Contractor X, which was revised by the Planning Manager and approved by the Senior Project Manager. The approved organizational structure chart is illustrated in Figure 5.1. The project team members with direct participation in the

Production Planning Process (PPP) (including the Planning Manager, Senior Project Building Engineer, Assistant Building Engineers, etc.) are highlighted. Moreover, the project team members identified with direct participation in the PPP were proposed as members of the ‘PLAN-SB implementation team’. This was later confirmed together with the ‘Implementation Project Charter’, to be addressed in Section 5.1.1.5.

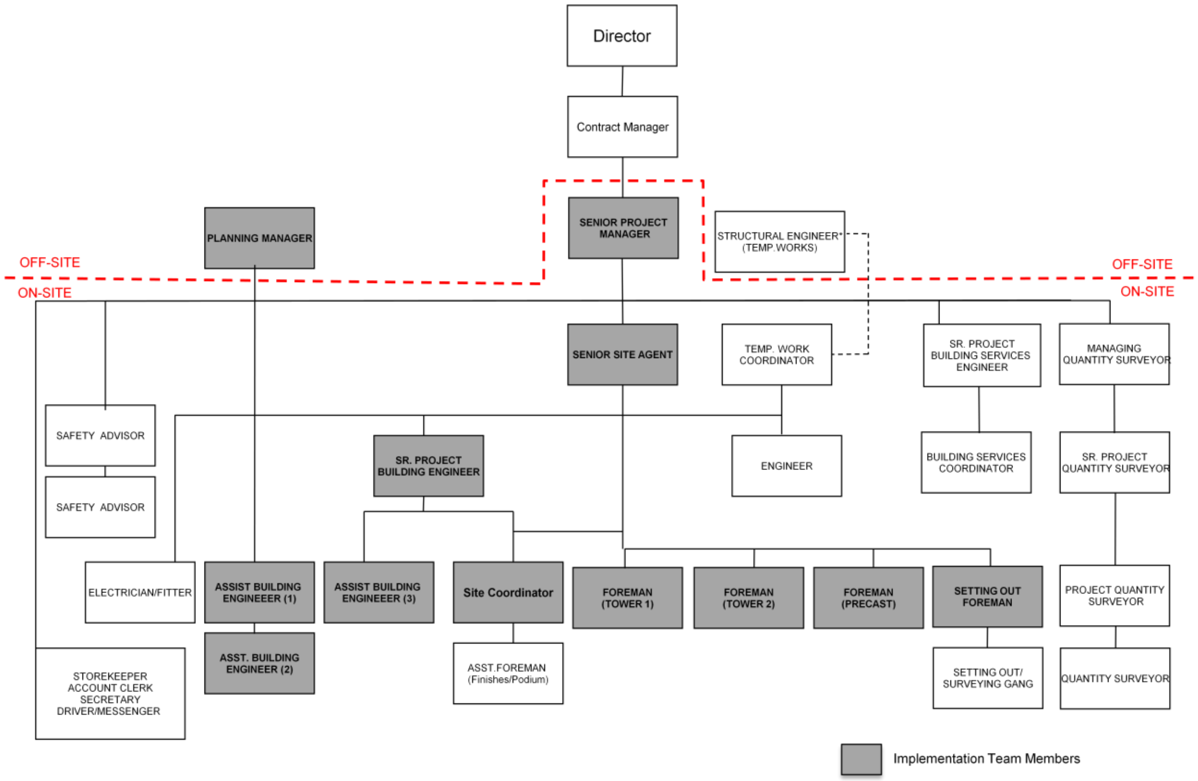

Figure 5.1 Project SB-T2 Organizational Structure Chart[2]

2 Three different Assistant Building Engineers were included in the PLAN-SB Implementation Team. Since they played different roles during the implementation process, these were differentiated with numbers (1), (2) and (3).

5.1.1.3 The SIPOC Diagram of the Production Planning Process (PPP)

The underlying principles of a SIPOC (Supplier, Input, Process, Output, Customer) diagram have been addressed in Chapter 4. The main purpose of developing a SIPOC diagram for the PPP is for obtaining the necessary information that helps to define the 'Inputs' (i.e. information required for the PPP) and the 'Customers' (i.e. the ones that use the production plans). This information helps to judge the quality of the 'Outputs' (i.e. production plans) not only by the process (i.e. PPP) but also by the quality of its 'Inputs' and the 'Customer' satisfaction. The SIPOC diagram for Project SB-T2 was developed by interviewing the 'PLAN-SB implementation team', since they were the project team members in close relation to the PPP. The SIPOC diagram of Project SB-T2 is presented in Figure 5.2.

Having identified the 'Customers' of the PPP by means of the SIPOC Diagram, it was necessary to know to what extent they were satisfied with the Outputs (i.e. production plans). As addressed previously in Chapter 2, there are two main Quality Characteristics (QC) in production plans: (1) reflecting the actual constraints and objectives of the construction environment, and (2) allowing the reduction of workflow variability. Therefore, 'Customers' were asked for their opinion based on a likert scale from 1 to 5 to define the level of their agreement in relation with the quality of production plans delivered in Project SB-T2, and their response will be recorded in a response table as shown in Table 5.1:

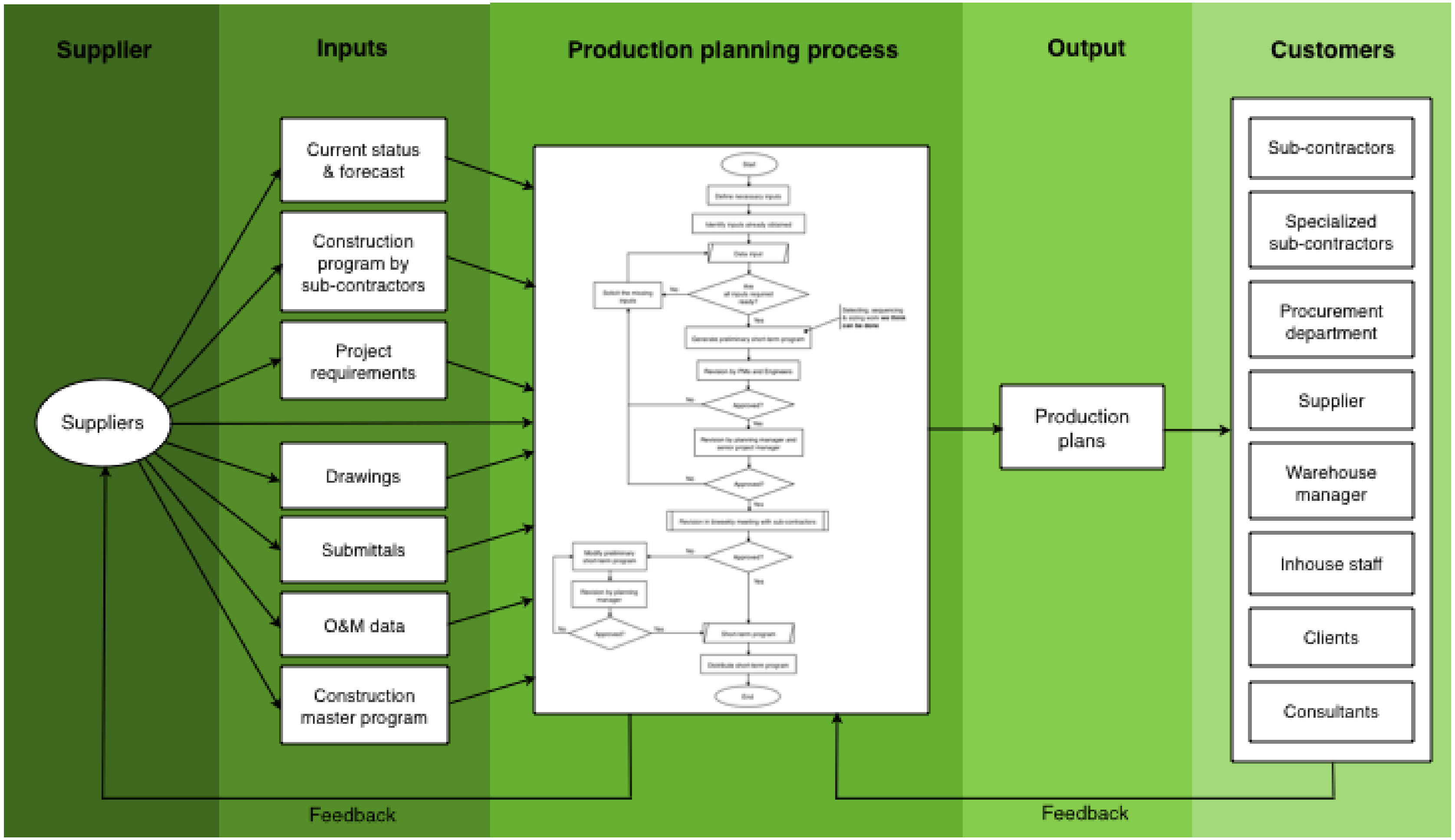

Figure 5.2 SIPOC Diagram

Table 5.1 Customer quality evaluation form of production plans

To what extent do you agree with the following statements about the production plans?

	SA	A	N	D	SD
QC (1) Production plans reflect the actual constraints and objectives of the construction environment	5	4	3	2	1
QC (2) Activities are executed in due time as specified in the production plans	5	4	3	2	1

(SA: Strongly Agree, A: Agree, N: Neutral, D: Disagree, SD: Strongly Agree)

'Customers' were personally approached by the Researcher and by the Assistant Building Engineer (1) to answer the customer quality evaluation form. A total of 11 responses from different 'Customers' were collected and the evaluation results are presented in Figure 5.3.

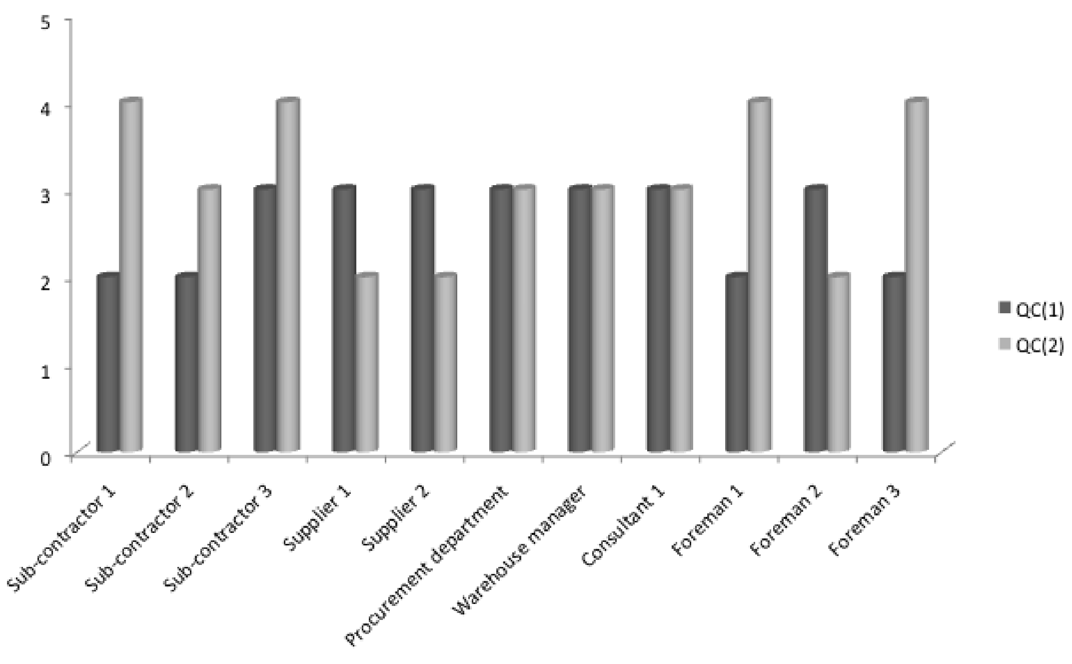

Figure 5.3 Quality evaluations of 'Costumers' on production plans

From the results observed in Figure 5.3, it is found that there are two main groups of ‘Customers’ with similar opinions. Sub-contractors and foremen are classified to the first group which mainly disagree with QC (1), however they agree with QC (2). These two ‘Customers’ are the ones leading the crews that are doing the physical work on site and therefore their responsibility is to execute the construction work as scheduled. It is not surprising that they manifested that activities are performed as scheduled even when constraints were not considered, as they may consider having skillful workers who effectively handle uncertainties on site.

Another group of ‘Customers’ formed by the suppliers, procurement department, warehouse manager and a consultant has a neutral agreement with both QCs, except for suppliers who disagree in QC (2). The ‘Customers’ of this group are characterized by providing the inputs in the construction process (e.g. materials and equipment) and in the case of the consultant by the form of information or a service. Therefore, they are highly related with the generation of constraints responsible for delaying the execution of activities (e.g. materials are not supplied, equipment breakdowns, submittals are out time). This may be the reason why their opinions are inclined to claim that constraints are considered in the PPP or that these do not exist at all, and there are still activities are not executed in due times as specified in the production plans. Considering the mean values of QC (1) and QC (2) (2.63 and 3.09 respectively), it suggests a “Neutral agreement”, which can be interpreted as having production plans in Project SB-T2 that are not regarded as bad quality plans but it is recognized that there are important rooms for improvement.

5.1.1.4 Flow Diagram of the Production Planning Process (PPP)

The development of a Flow Diagram as a visual representation that helps to define all major steps in a process brings specific benefits related to the better understanding of the interfaces between various contributors in the process and how the process itself flows through the organization. The development of a Flow Diagram for the PPP is proposed in this section to allow coming to a consensus regarding the steps of the process and to identify critical and problematic areas for improvement. For accurately developing the Flow Diagram two approaches were used in order to obtain information that help to truly represent it, as follows: Firstly, interviews with the Planning Manager and the Assistant Building Engineer (1) and (2) were carried out for obtaining information necessary for drafting the PPP flow diagram in Project SB-T2. These three project team members were selected since they are the ones responsible for creating the preliminary production plans that are later submitted for approval in following stages. A draft of the Flow Diagram was jointly prepared by the Researcher and the Assistant Building Engineer (1) and (2). Secondly, the draft was subjected to a verification process by the researcher through direct observations and also by collecting the comments, modifications and finally the approval of the Senior Site Agent and the Senior Project Manager. The final version of the PPP flow diagram is presented in Figure 5.4.

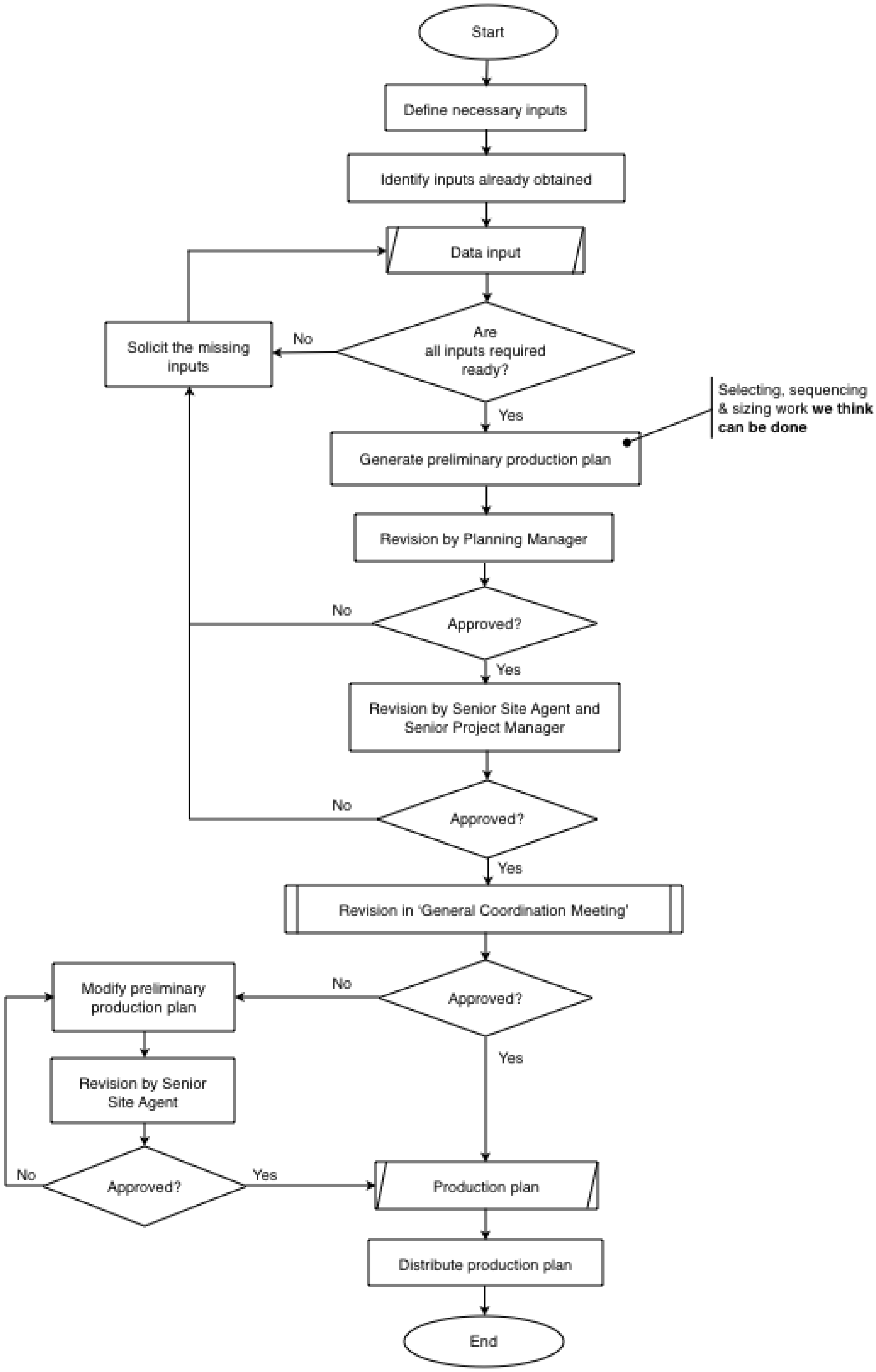

Figure 5.4 PPP Flow Diagram

As appreciated in Figure 5.4, the first two steps are related to the definition and acquisition of necessary inputs for generating the production plans. Having all inputs ready, the next process is to generate a preliminary production plan following the traditional approach of Push Planning System (i.e. selecting, sequencing and sizing the work, which has been introduced in Chapter 2). The preliminary production plan was later past forward for revision and approval to the Planning Manager. The Senior Site Agent and the Senior Project Manager make a second stage of revision and approval before the production plan is presented to the 'General Coordination Meeting'. The 'General Coordination Meetings' were held every two weeks with concerned project team members, sub-contractors and suppliers. The production plan is discussed for approval in the meeting. If the production plan is approved, it will be distributed to the 'Customers' as specified in the SIPOC Diagram. Otherwise, necessary modifications are made by Assistant Building Engineer (1) and (2) and revised and approved by the Senior Site Agent, followed by the distribution of the production plan.

5.1.1.5 Implementation Project Charter of PLAN-SB in Project SB-T2

The Project Charter is a working document for defining the terms of reference for a specific project. The principles of Project Charter have been introduced in Chapter 4. A Project Charter for the implementation of PLAN-SB in Project SB-T2 was proposed, as shown in Table 5.2, in order to help to define the necessary resources and boundaries that would in turn help to enable and enhance the possibilities of systematically achieve the steps of PLAN-SB implementation framework. The 'Implementation Project Charter' for PLAN-SB helped to give a common understanding of the perceived problems, goals statements, the scope, and who are implementation team members and the timing. The charter was developed by the Researcher and approved by the Senior Project Manager and the Planning Manager.

Table 5.2 Project Charter

Building Project	Project SB-T2		
Implementation Project	PLAN-SB-A		
Project Type	Improvement of the Production Planning Process (PPP)		
Problem	Production plans do not effectively reflect the actual constraints and objectives of the construction environment and do not allow reduction of workflow variability		
Goal Statement	To identify and eliminate the constraints that impede to increase the reliability of production plans and meet the objectives of the project.		
Project Scope	Study production performance data and reasons for non-completion of activities to determine the special and root causes of variability and improve the PPP by eliminating them.		
Implementation Team Members	Researcher Senior Project Manager Planning Manager Senior Site Agent Senior Project Building Engineer Assistant Building Engineer (1, 2 and 3) Site Coordinator Foreman (Tower1) Foreman (Tower 2) Foreman (Precast) Foreman (Setting Out)		
Defect Definition	Percent Plan Incomplete (PPIC)		
Perceived average Percent Plan Complete (PPC) value by implementation team members	50-70%		
Timing	First Stage	Second Stage	Third Stage
	Define & Measure	Analyze & Improve	Control
	13/03/09	05/05/09	09/06/09

5.1.1.6 Potential areas identified for improvement

Information obtained during the Define step and contained in the Organizational Structure chart, SIPOC diagram, Flow Diagram and Project Charter provides enough elements for better understanding of PPP and enabling the identification of potential areas for improvement. The potential areas for improvement in PPP of PLAN SB-T2 are identified as follows:

1. ***First revision and approval stage of preliminary production plans*.** It was appreciated that the Assistant Building Engineers (1) and (2) were the main responsible project team members for preparing the preliminary production plans while they were partially supervised by the Planning Manager. Assistant Building Engineer (1) and (2) are fresh graduates who previously worked for a period of six months in the 'Head Office' as Assistant Planners responsible for planning activities and generating Master Schedules of varied projects. This was regarded as a training process before they were assigned to Project SB-T2 for generating the production plans. In fact, the Planning Manager advised that this is a common practice for almost all projects of similar scale under the execution of Contractor X. In this sense, the first revision and approval of the preliminary production plans made by the Planning Manager as appreciated in the Flow Diagram was regarded as highly important. Such consideration was made since it was in this step where possible mistakes incurred by the two planners with a limited experience could be identified. However the Planning Manager acted as an off-site project team member who besides Project SB-T2 was

also looking after other projects within Contractor X. Therefore, it was suggested that he might not have all the necessary elements to accurately judge in such level of detail the quality of production plans.

2. ***Traditional Push Planning System.*** From the Flow Diagram in Figure 5.4 it was appreciated that the PPP in Project SB-T2 followed a traditional Push Planning System. Production plans provided from each sub-contractor (the work they **think can be done**) were analyzed for selecting and sequencing the activities in order to integrate them in a single production plan regarding the overall milestones included in Master Schedule (the work that **should be done**). However, this analysis was limited to selecting, sequencing and sizing without analysis on elimination of constraints to the activities (the work they **know with higher certainty can be done**). This is also a major reason why production plans after being jointly analyzed in the 'General Coordination Meetings' resulted with several amendments.

3. ***Final revision and approval of production plans***. From Figure 5.4 it was also noticed that if the production plans were not approved during the 'General Coordination Meetings' that according to the team members happened to majority of production plans. Modifications were taken by the Assistant Building Engineer (1) and (2) and revisions were taken and approved only by the Senior Site Agent.

5.1.2 Measure step

Having defined the PPP of Project SB-T2 in the previous section, of equal importance is to measure its performance. It is precisely by the use of performances measurements what makes possible the analysis of attributes of a process for improving its efficiency and effectiveness. In this sense, three metrics, namely, Percent Plan Complete (PPC), rolled PPC, and Sigma Level, with different qualities each one are proposed for measuring the performance of the PPP. The process of calculating the three metrics has been introduced in Chapter 4. The calculation of Percent Plan Complete (PPC), rolled PPC and Sigma Level requires the collection of specific data from Project SB-T2. Moreover, data related to reasons for non-completion of activities was also collected in order to prioritize areas for improvement by using the Pareto Chart tool.

5.1.2.1 Data Collection

Data collection process ensures providing with the information required to calculate the Percent Plan Complete (PPC), rolled PPC, and Sigma Level. The information will also be used to analyze the priority of the areas for improvement. Data was collected during the three stages of PLAN-SB implementation, which took 17 weeks. The First Stage data was collected from Week 1 to Week 5, which reflects the performance measurements before any attempt of improvement in the PPP was made. The Second Stage data was collected from Week 6 to Week 10 in order to measure the PPP performance after improvement actions taken to the PPP. And the Third Stage data was collected from Week 11 to Week 17 to verify whether improvements were maintained (if any). Data was collected from defined sources such as: master schedule, production plans and activity descriptions and total duration times. The information tells the expected daily completion/progress of activities. The real progress of the activities and the reasons for non-completion (if any) were recorded from the two towers of Project SB-T2 by the Foremen and revised by the Site Coordinator and Assistant Building Engineer (3). In order to facilitate the data collection process, the tool 'PPC and reasons for non-completion check sheets' was developed for use, which has been presented in section 4.4.2. Data was collected on a daily basis and used to calculate the daily PPC. In the case of reasons for non-completion (Reasons-NC), these reasons were recorded using the Reasons ID which is presented in Table 4.2. These reasons are used in the Pareto Charts for further analysis as presented in following sections.

5.1.2.2 PPC vs. rolled PPC Analysis

In building projects, the construction process is divided into various activities using a particular Work Breakdown Structure (WBS). If an activity is not completed in one particular day as scheduled, it will reduce the output for the particular day planned, namely, the PPC will be lower than 100%. As that activity will have to be completed next day, it will in turn affect the output of the next day. Thus, a PPC value lower than 100% for one day will affect the output for the next day. If this scenario continues, for example for over a week's time, with a lower PPC on each day, it will lead to an overall output much less than planned at the end of the week. Thus, the performance metric PPC is able to project the inefficiency of the process in daily basis.

PPC measurement on a daily basis is effective, but planning for production on daily basis is very tedious and close to impossible considering the effort and cost that would be required. This is especially true in the residential building industry, where the competition is based on the final cost of the product, thus it is impractical to require such a tedious process. Therefore, evaluation of the PPP on a weekly basis is considered more appropriate. In this sense, a 'Weekly PPC' value is considered proper for measuring the PPP performance and for its improvement analysis.

However, with the purpose of recognizing the daily inefficiencies by using daily PPC in the process and comparing it with the weekly performance, an advanced metric named rolled PPC is introduced, which has been presented in Chapter 4. The differences between 'Weekly PPC' and 'rolled PPC' can be better explained with an example. Consider data of 'Tower 1' in 'Week 3' obtained from Project SB-T2 and contained in Appendix A, with the sample data is shown in Table 5.3.

Table 5.3 PPC and rolled PPC for 'Tower 1' in 'Week 3'

Tower 1	14 April	15 April	16 April	17 April	18 April	20 April	PPC (%)	
							rolled	Weekly
Activities planned	23	21	20	22	21	19		
Activities completed	13	11	12	11	10	11		
PPC (%)	56.52	52.38	60.00	50.00	47.62	57.89	2.45	54.06

The table above shows the activities planned and completed for a week period. It also shows the PPC value for each day. The 'Weekly PPC' is an average of the daily PPC values for the week. The data for this week shows an average PPC of 54.06% and this is calculated by taking and average of all the daily PPC values.

Daily PPC values in Table 5.3 shows that on ‘14 April’, 13 out of 23 activities were completed giving a PPC value of 56.52%. On ’15 April’, 11 out of 21 activities were completed giving a PPC value of 52.38%. The incomplete activities on ’15 April’ were due to the extra work performed to complete the previous day’s work. Thus, the 44% of the work expected to be completed on ‘14 April’ was actually completed on “15 April’. Thus, the PPC value for 2 days hides the extra work done owing to incomplete work on the previous day. By multiplying PPC of ‘14 April’ with PPC of ‘15 April’ can accurately reflect this. So, at the end of ’15 April’ the PPC should be 29.60% (56.52%*52.38).

The above multiplication procedure is the same procedure for arriving at the rolled PPC metric described in Section 4.4.2. The weekly ‘rolled PPC’ is a value obtained by multiplying the daily PPC values for the week. For example, the weekly rolled PPC for the data of ‘Week 3’ in Table 5.3 is 2.45% (56.52%*52.38%*60%*50%*47.62%*57.89%). Thus, the rolled PPC metric gives a more accurate value for measuring the performance of the process without hiding the rework because of incomplete tasks on the previous day(s).

The metric rolled PPC is developed from the rolled yield metric suggested in the Six Sigma methodology. This metric focuses in revealing the hidden work or rework in a production process. Hidden work or rework reduces the output of a process, thus it should be eliminated. Therefore, rework or hidden work should be taken into account when measuring performance of production planning. The rolled PPC could be regarded as a very strict performance metric for measuring production performance in construction industry, The adoption of rolled PPC can better measure the improvement from day-to-day performances after the implementation of PLAN-SB, which can be used to compare with the improvements achieved in terms of Weekly PPC.

Thus, in order to measure the performance of the PPP during the First Stage, data collected from Week1 to Week5 was used to calculate the daily PPC, Weekly PPC and rolled PPC values. These values were used to plot a graph of Weekly PPC vs. rolled PPC for 'Tower 1' and 'Tower 2' respectively for analysis purposes as seen Figures 5.5 and 5.6.

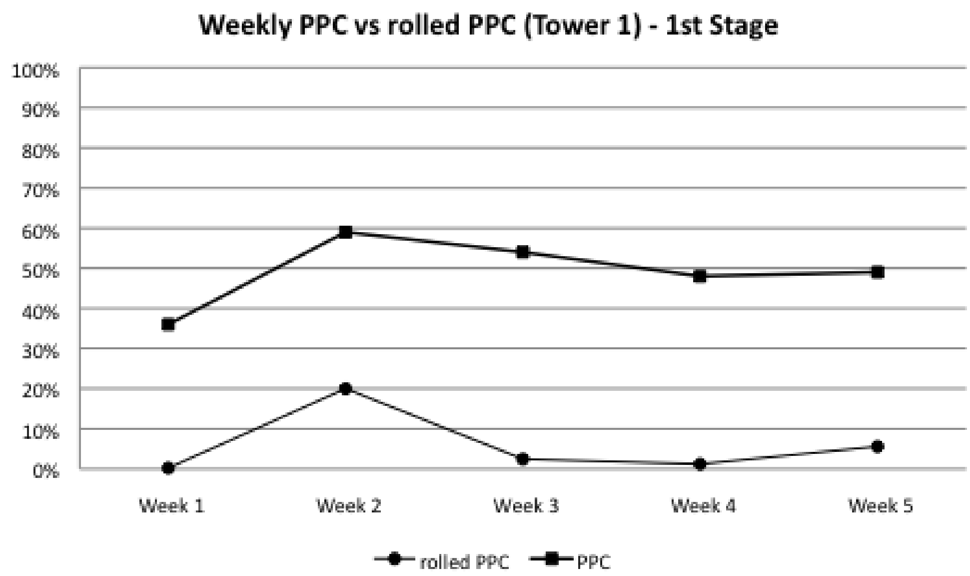

Figure 5.5 Weekly PPC vs. rolled PPC (Tower 1) – 1^{st} Stage

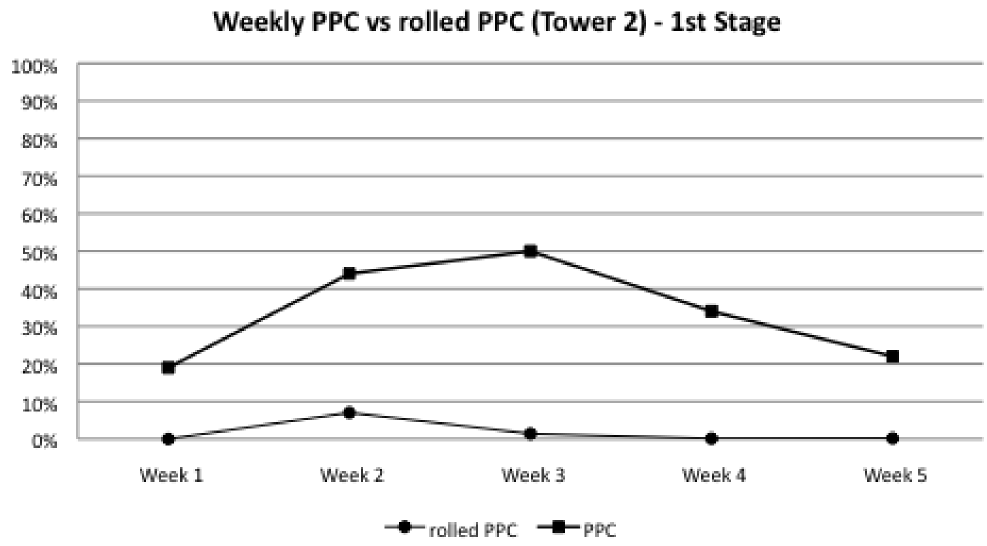

Figure 5.6 Weekly PPC vs. rolled PPC (Tower 2) – 1st Stage

From the graphs it is appreciated that Tower 1 had a notable better performance than Tower 2. Tower 1 reached the highest Weekly PPC value of 59%, while Tower 2 could only reach a Weekly PPC value of 50%. These values also varied in a higher range in Tower 2, with a difference of 31% between its highest and its lowest (50% - 19%), while in Tower 1 this difference was only 23% (59% - 36%). It means that Tower 1 could maintain a more reliable performance over the five weeks. The average PPC in the First Stage period also showed a better performance in Tower 1, reaching 49.20%, while this value in Tower 2 was of 33.80%.

Moreover, by referring back to the 'Implementation Project Charter' of PLAN-SB in Section 5.1.1.5, the perceived average PPC values from the 'Implementation team members' ranged from 50% to 70%. However, it is interesting to note that, according to the data collected from Project SB-T2 during the First Stage, these values do not correspond to the PPC values obtained during the First Stage as seen in Figures 5.5 and 5.6, evidencing the poor accuracy of their perceptions about the PPP performance. Results on the PPP performance obtained during the First Stage were informed to the ‘Implementation team members’ and feedback was obtained regarding the low PPP performances and in particular the noticed difference in performance between Tower 1 and Tower 2. The members acknowledged a lower progress and less reliable production plans in Tower 2 than in Tower 1. They also explained that such facts occurred because they were lacking of enough qualified workers, and when crews were available, priority was given to Tower 1 since it had more facilities to be built than Tower 2. However they also acknowledged that the progress of the two towers should be synchronized since joint milestones existed between the two Towers.

Considering the rolled PPC values, it is appreciated that these values from Tower 2 are much lower than that in Tower 1. The rolled PPC value even reached to 0% in Tower 2. A value of 0% for rolled PPC indicates that the week had at least one day with a PPC of 0%, and a value of 100% for rolled PPC indicates that the week had 100% PPC on all days of the week. This clearly shows the effectiveness of the rolled PPC metric in measuring the performance of the PPP for both the best and the worst cases.

5.1.2.3 The calculation of Sigma Level

As discussed in Chapter 2, Sigma Level metric can reflect the PPP performance in a single value. It allows benchmarking different PPP performances. Sigma Level, as a normalized value, can be used for benchmarking the PPP performance before and after its improvement, between types of activities, between one project to another and can also be extended to compare with other processes from other industries. Thus, having calculated the daily PPC values, the Sigma Level for the PPP can be calculated, and the calculation principles have been explained in Section 4.4.2.

By adopting the data collected, Sigma Levels were calculated for each tower and the values are presented as follows:

Sigma Level for Tower 1: **2.54 σ**

Sigma Level for Tower 2: **2.20 σ**

From the Sigma Levels presented above, it is appreciated that the clear differences in performance between Tower 1 and Tower 2 exist, which have been evidenced by the PPC values calculated earlier. Thus, such appreciation suggests that Sigma Level metric can be used for benchmarking the overall PPP performance before and after actions for improvement in the Second Stage in order to measure how effective the improvement actions were. Nevertheless, it is also appreciated that the PPP Sigma Levels obtained in this First Stage are far below to what is considered a ‘World Class” or even a “High Quality” company process according to the specified Sigma Levels scale (Basu 2009)[3].

5.1.2.4 In-depth understanding of the potential areas for improvement

Results obtained in the measurement process during the First Stage are used to support or disregard potential areas for improvement, which were previously identified in the Define step. For instance, low PPC values suggested unrealistic production plans which are unable to reflect the actual constraints of the

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[3] According to Harry and Schroeder (2006), companies owning processes with a sigma value of 1σ are “non-competitive”, from 2σ to 3σ are “Industry Average”, with 4σ are “High Quality” and from 5σ to 6σ are “World Class”.

construction environment. The unrealistic plans were possibly derived from a defective planning practice coupled with a deficient revision and approval process (supporting potential area for improvement 1 and 3). Moreover, high variability in the Weekly PPC values over the First Stage period and the low rolled PPC values obtained suggested deficiencies in the PPP for generating production plans able to control variability in the workflow (supporting potential area for improvement 2). Therefore, the three potential areas for improvement were supported, including first revision and approval stage of preliminary production plans, traditional Push Planning System, and final revision and approval of production plans, as introduced in Section 5.1.1.6. However, it is in the Second Stage of PLAN-SB implementation where areas for improvement are confirmed and prioritized after a more comprehensive analysis on reasons for non-completion of activities and daily PPC performances analysis by using the Pareto Chart and P-Chart tools respectively.

5.2 Second Stage (Analysis and Improve)

Second stage of PLAN-SB implementation involves Analysis and Improve steps. In the Analysis step, the information obtained in the Define and Measure steps was analyzed for identifying the variations in the workflow of Project SB-T2 and the causes of the variations in order to prioritize areas for improvement in the PPP. Having identified and prioritized areas for improvement, alternative processes of PPP were proposed towards their improvement. Moreover, production performance data and reasons for non-completion (Reasons-NC) of activities were collected as done during the First Stage for obtaining PPC values and Sigma Levels, and consequently being able to verify if improvement was achieved after improvement actions.

5.2.1 Analysis step

The Analysis step according to PLAN-SB implementation framework as presented in Chapter 4 consists of a series of analyses by using different tools. Firstly, by using Pareto Charts, reasons for non-completion are categorized and critical areas for improvement are identified. Secondly, P-Charts are used for identifying special variations in the workflow and their corresponding causes. Thirdly, Cause and Effect Diagrams are used for finding the root causes of the most frequent reasons for non-completion of activities as identified in Pareto Charts. Finally, opportunities for improvement are confirmed and prioritized.

5.2.1.1 Pareto Chart Analysis of Reasons-NC

Pareto Chart is a tool that ranks or stratifies data from highest to lowest. The principle of the tool has been introduced in Section 4.5.1. Pareto Charts are used in this study to stratify the reasons for non-completion (Reasons-NC) according to their frequencies in Project SB-T2. The stratification of Reasons-NC by their frequencies facilitates their analysis and optimizes efforts when prioritizing them towards their elimination. In order to prioritize Reasons-NC, the '80/20 rule' is applied as introduced in Chapter 4. This rule has been especially effective when used for optimizing efforts oriented to the improvement of processes. For instance, Mozilla Firefox (2006) and Microsoft (2010) noted that by fixing the top 20% of the most reported bugs[4], 80% of the errors and crashes were eliminated.

In this study, the Reasons-NC recorded during the First Stage (from 30- March to 4-May) were stratified according to their occurring frequencies in the construction

[4] A software bug is the common term used to describe an error in a computer program or system that produces an incorrect or unexpected result

process and were used to identify the causes related to majority of incomplete activities. Pareto Charts help to illustrate this information graphically. Figures 5.7 and 5.8 presents the Pareto Charts for Tower 1 and Tower 2 respectively, where Reasons-NC are referred by their corresponding ID number as assigned in Table 4.2. The number of times each Reason-NC has caused an incomplete activity is the incomplete frequency, the percentage this frequency represents and the cumulative percentage is the information included in the Pareto Charts and used for analysis.

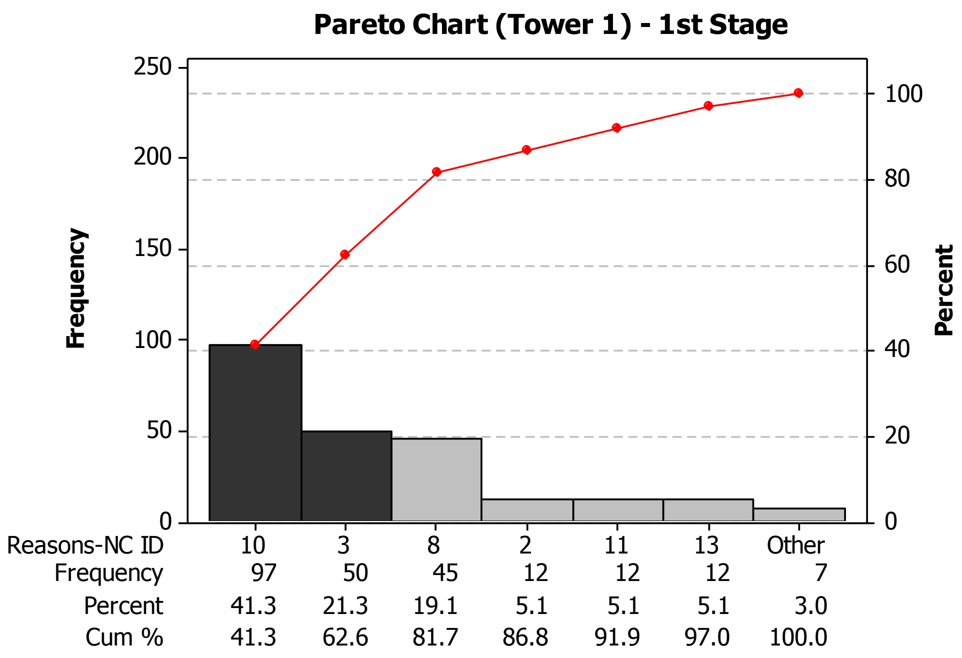


Figure 5.7 Pareto Chart of reasons for non-completion (Tower 1) – 1st Stage

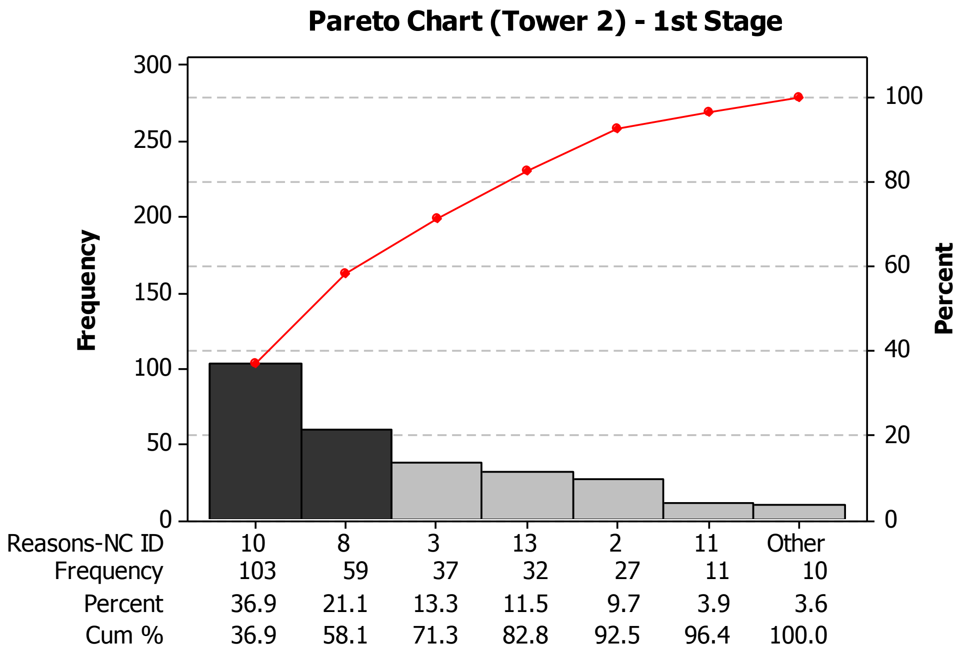


Figure 5.8 Pareto Chart of reasons for non-completion (Tower 2) – 1st Stage

A primarily analysis on the figures above demonstrated conformity of data with the '80/20' rule in both Towers. In Tower 1, 3 out of 13 reasons (23%) represented an accumulated of 81.70%, while in Tower 2, 4 out 13 reasons (30%) represented an accumulated of 82.8%. Therefore, according to the 80/20% rule, the analysis should be focused on Reasons-NC (10), (3) and (8). It is noticed that 'Lack of continuity or prerequisite work not completed' with Reasons-NC ID (10) is the reason that caused most of the incomplete activities in both Towers. Lack of continuity means that an activity could not be undertaken due to the work that needs to be completed before. This single reason represented 41.30% of frequencies in Tower 1 and 36.90% in Tower 2, which suggests bad quality production plans that are not reflecting the actual constraints of activities. In other words, activities included in the production plans are not constraint free.

Therefore, these activities are not performed as planned, which consequently affected the following activities. ‘Moves to other work area’ Reason-NC with ID (8) and ‘waiting for workers/tools/equipment’ Reason-NC with ID (3) represented the second and third important reasons with highest frequency respectively. The high frequency of these two Reasons-NC supports the opinions perceived by the project team members for a poor performance in Tower 2 as addressed in the First Stage (i.e. lack of workers and priority given to Tower 1). However, it was found that the same reasons also represented the second and third highest in Tower 1. Therefore, the high frequencies of Reason-NC (8) and (3) in both Towers suggest an additional cause. A further analysis was made and it was appreciated that the project was experiencing a transition from activities mainly related to the superstructure of the Towers to more varied activities related to the building façade, architectural finishing and services installations. Activities related to the superstructure of the Towers were characterized by being more repetitive, with fewer procedures and requiring less quantity of workers than the subsequent activities. Thus, the increased demand of workers, materials and equipment evidenced a poor quality PPP provoking an excessive movement of workers from Tower 2 to Tower 1 and vice versa. This also affected the lack of certainty of when and where materials and equipment should be administrated.

5.2.1.2 P-Chart Analysis

Pareto Charts have helped to identify the main reasons causing variability in the workflow (i.e. activities incomplete). However, variations are inherent in any process and these can be attributed to either common causes or special causes. Common causes are those causes that are built into the process and can be eliminated by means of reengineering or designing a different process. Whereas, special causes are those that create sudden variations in the process and can be eliminated without changing the overall process. Control chart is a popular method for determining the special causes and it is used here to statistically determine such causes and means to eliminate them. In Section 4.5.1, Control Charts were discussed and a description of P-Chart and its appropriateness for this data was presented. In order to focus on incomplete activities and find causes for the incompletion, the measure Percent Plan Incomplete (PPIC) is introduced to replace the Percent Plan Complete (PPC). PPIC is the ratio of total number of activities incomplete to the total number of activities planned to be complete. This has been addressed in Chapter 4.

By using the data related to the incomplete activities recorded during the First Stage period, as presented in Appendix A, P-Charts were plotted for Tower 1 and Tower 2 and these are presented in Figures 5.9 and 5.10 respectively. Upper Control Limit (UCL) and Central Line (CL) were calculated by using the equations listed in Section 4.5.1. The change of Lower Control Limit (LCL) to Lower Specification Limit (LSL) of 0% aims to focus the analysis on those PPIC values out of control due to high number of activities incomplete. And, the variations appreciated in UCL are related to the variations in number of activities assigned for each day. Thus, on a given day, the PPIC should not be more than its UCL value. Moreover, 4 different tests are applied to the flow of PPIC values plotted in the P-Chart as introduced in Section 4.5.1. These tests help to detect special variations by means of identifying positive or negative trends of PPIC values in the P-Chart. Thus, when a special variation is detected, PPIC value will move towards a positive or negative trend.

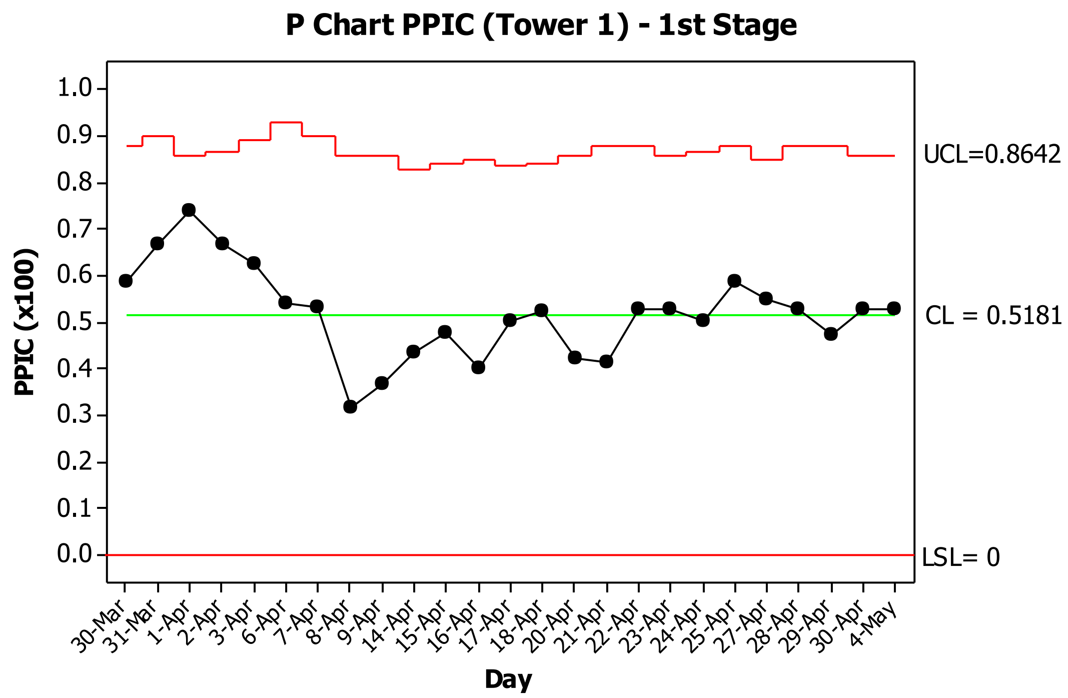


Figure 5.9 P-Chart PPIC (Tower 1) – 1st Stage

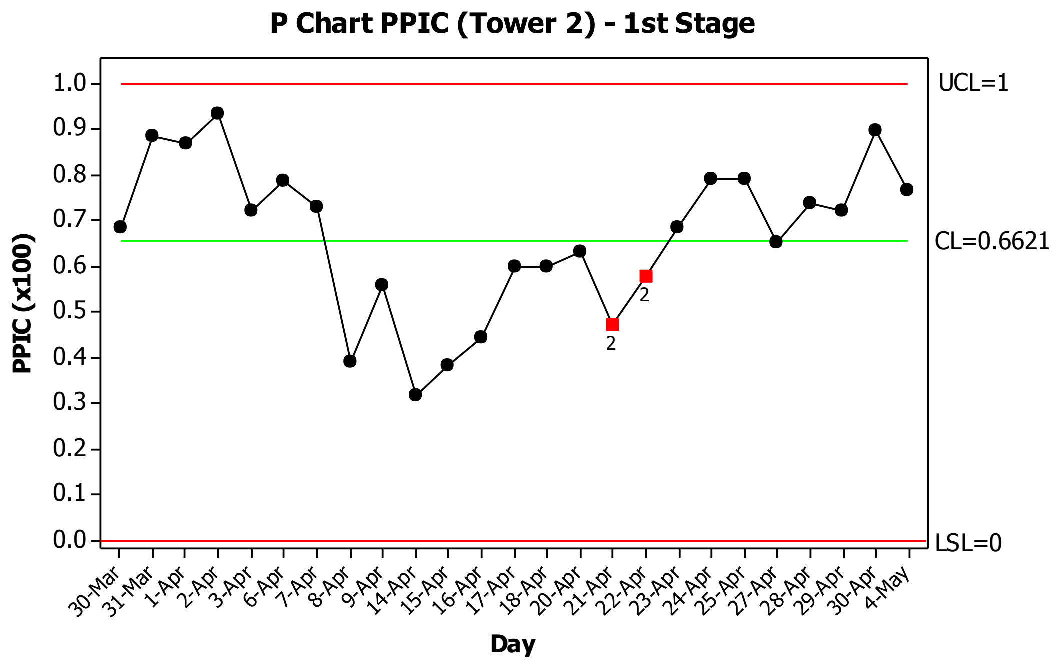


Figure 5.10 P-Chart PPIC (Tower 1) – 1st Stage

Overall Flow Analysis

From Figures 5.9 and 5.10 it is appreciated that more variability existed in the PPIC values obtained in Tower 2 than in Tower 1. The variability of a difference of 61.51% between its highest and its lowest was found in Tower 2 (93.33% - 31.82%). And in Tower 1 this difference was only 42.1% (73.68% - 31.58%). Consequently, a higher CL resulted in Tower 2 with value of 66.41%. A high CL coupled with high variability of PPIC values provoked a UCL of 100% in Tower 2. A UCL of 100% means that only if all activities are not completed as planned in a single day the process will be considered out of control. In the case of Tower 1, a lower UCL was resulted due to lower PPIC values and lower variability achieved, therefore a daily PPIC higher than 86.42% is considered out of control.

Test Analysis

Figure 5.10 shows that a special variation is evidenced. This special variation is related to an improvement trend of PPIC values which was maintained for at least 9 consecutive times under CL (i.e. Test #2). For understanding the causes behind this improvement the following analysis was made:

It can be appreciated that the improvement started in the transition between Week 1 (30-March to 6-April) and Week 2 (07-April to 09-April). Thus, it is relevant to identify the main frequency reductions of Reasons-NC between these two weeks for determining what triggered such improvement. By examining the compilation of Reasons-NC recorded during the First Stage and included in Appendix B, it was found that from Week 1 to Week 2 the main frequency reductions happened to Reasons-NC: ‘waiting for workers/tools/equipment’ (3), ‘lack of continuity’ (10) and ‘other’ (13)[5].

General Variations Analysis

1. Even when an important improvement was recorded in Tower 2 as evidenced by Test #2, it was not maintained for long. In the transition between Week 3 (14-April to 20-April) and Week 4 (21-April to 27-April) the PPIC values went back over the CL, reaching as high as 89.47%. These increments of PPIC values are attributed to the increment of frequency in Reasons-NC ‘waiting materials from supplier’ (2), ‘waiting for workers/tools/equipment’ (3), ‘moves to other work area’ (8) and ‘lack of continuity’ (10).
2. Similar improvement from Week 1 to Week 2 recorded in Tower 2 was also present in Tower 1. However this was not enough to trigger the test signal #3 (i.e. 6 consecutive PPIC values, all increasing or all decreasing). The main frequency reductions happened to the Reasons-NC: ‘waiting for workers/tools/equipment’ (3) and ‘lack of continuity’ (10).

From the above analyses, it is found that the main special causes related to the variability in the workflow are Reasons-NC (3), (8) and (10). It is interesting to note that these are the very same reasons previously identified in the Pareto Charts as the ones with higher frequency. Such facts suggest that Reasons NC (3), (8) and (10) represent the causes that are both with higher prevalence in the process and highly influencing the variability in the workflow. Thus, the following

[5] Due the unfamiliarity with the ‘reasons for non-completion’ list (Table 4.2) given to the foremen for recording the data during the first week, and excessive use of ‘other’ (13) as a reason for non-completion was experienced. Thus, its frequency reduction is directly related to the better use of the tool but alien to the PPP itself.

analysis will concentrate in these three critical Reasons-NC with the aim to find out their root causes.

5.2.1.3 Cause and Effect Diagram Analysis

Pareto Charts and P-Charts have helped to identify the reasons for non-completion (Reasons-NC) of activities with higher frequency and generating critical variations in the workflow in Project SB-T2. Therefore, the elimination of these specific causes of variability represents a great step towards the reliability improvement of production plans. However, it is acknowledged that these Reasons-NC are just the effects of the root causes which are more difficult to identify. Therefore, a truly improvement could only be achieved by identifying and eliminating the root causes in order to lead to the prevention of recurrence of the effects (i.e. Reasons-NC).

The identification of root causes involves a more in-depth analysis for each specific Reason-NC. Cause and Effect diagram is considered an effective tool for this analysis. The system PLAN-SB adopts the tool for identifying, sorting, and displaying possible root causes related to the critical Reasons-NC in Project SB-T2. The 5 steps for developing the Cause and Effect diagrams were followed according to the principles introduced in Section 4.5.1 and the diagrams are presented in Figures 5.11, 5.12 and 5.13.

Step 1 –Identify and clearly define the problem/effect to be analyzed

Reasons-NC with higher prevalence in the process and highly influencing the variability in the workflow are selected for the analysis. They are as identified in the Pareto Chart and P-Chart Analysis: ‘lack of continuity’ (10), ‘waiting for workers/tools/equipment’ (3), and ‘moves to other work area’ (8).

For identifying the root causes, the technique ‘5 Whys’ is adopted. The ‘5 Whys’ is a question-asking method used to identify major categories of causes contributing to an effect and increasingly identify more detailed levels of causes under the same category (Microsoft Corporation 2002). The ‘5 Whys’ technique facilitates to check any effect and ask ‘Why?’ and ‘What?’ has caused this effect? Very often the answer to the first Why will prompt another Why and so on, thus the name ‘5 Whys’ technique is called. The technique was applied with the ‘implementation team members’ and subcontractors for obtaining their opinion on the different causes and effects relationships underlying each Reason-NC under analysis. For the analysis about the Step 2, Step 3 and Step 4, the Reason-NC (8) ‘move to other work areas’ is used as an example:

Step 2 – Identify the main categories of causes contributing to the problem/effect

In order to identify the main categories of causes under which more possible factors for ‘move to other work areas’ is occurring, information are obtained by asking the first ‘Why’: Why did workers moved to other work areas?

The answers obtained were mainly related to Materials, Management, Transportation and Site. Therefore, these are the main categories from which further causes will be identified in the next step.

Step 3 – For each main category, identify other specific factors

For identifying further more causes under each category, another Why was asked: Why ‘Site’ is a reason for moving to other working areas?

The answers obtained were: the working area is overcrowded, site conditions are not as expected, there is no access to the site and the site is not safe enough

Step 4 – Identify increasingly more detailed levels of causes and continue organizing them under the related causes categories.

In this Step 4, causes are furthermore identified until there is a consensus on what is the root cause of the effect under analysis. However, it should be acknowledged that levels of detail of root causes identified in this Step could lead to identifying the problems causing the root causes. These problems are related to specific processes such as safety management, procurement, and supervision. The purpose of this study focus on helping to avoid such causes in future activities by means of a better planning system which can help to detect the causes before occurrence. Therefore, causes identified in Step 2 and Step 3 are considered detailed enough for screening activities in order to detect constraints related to such causes.

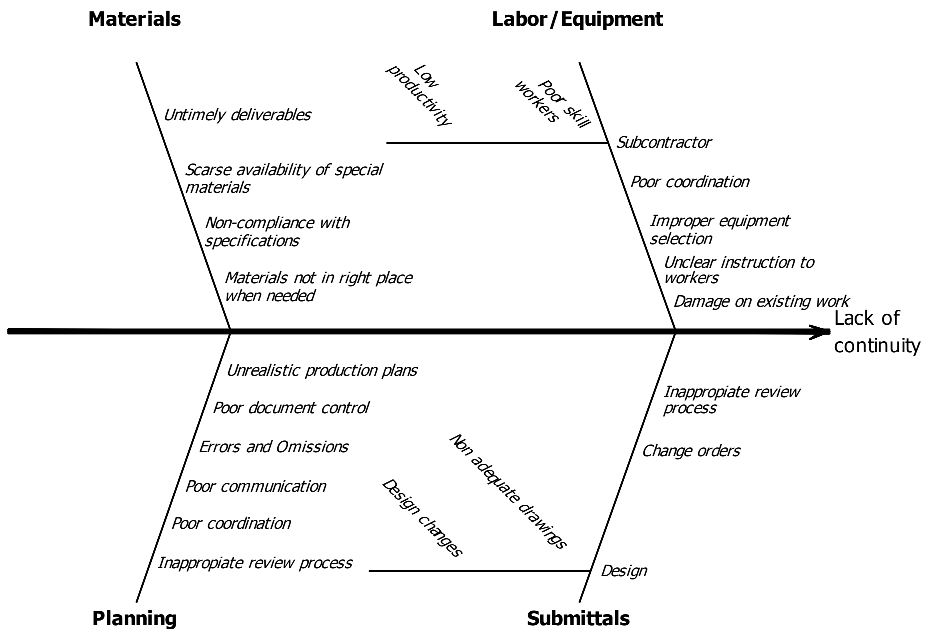


Figure 5.11 Cause and Effect diagram for 'Lack of Continuity'

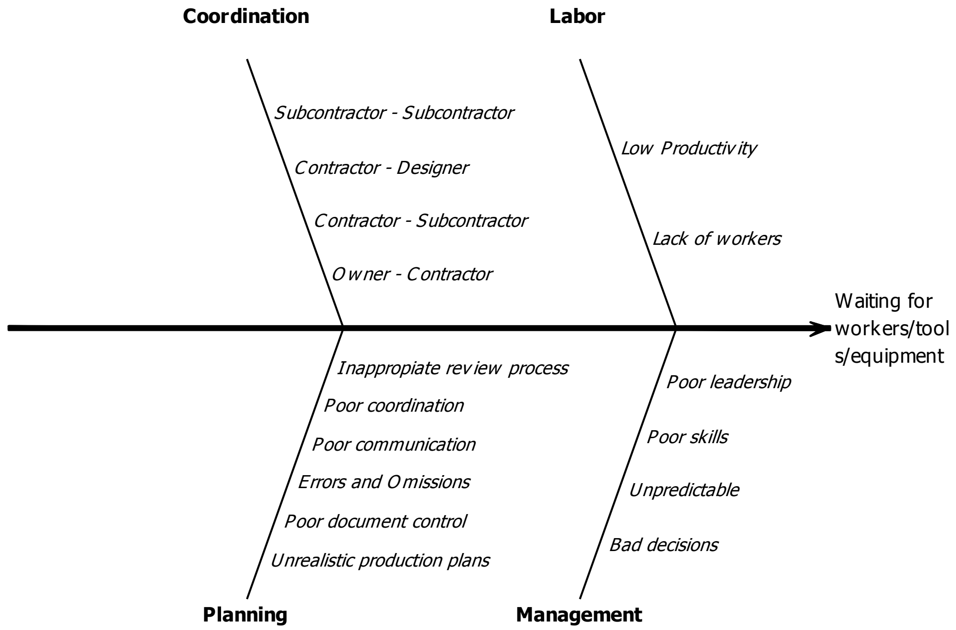


Figure 5.12 Cause and Effect diagram for ‘Waiting for workers/tools/equipment’

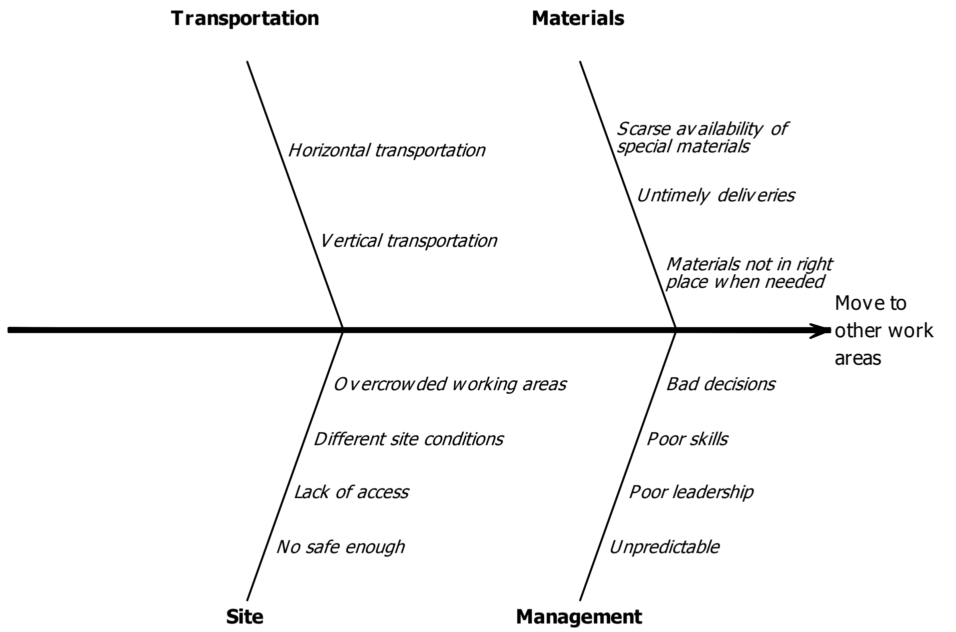


Figure 5.13 Cause and Effect diagram for ‘Move to other work areas’

Step 5. Analyze the diagrams

In Figures 5.11, 5.12 and 5.13 the main causes related to the Reasons-NC with high frequency during the First Stage are shown. According to the characteristics owned by each main cause identified, the causes can be categorized either as causes related to inputs or processes. Main causes such as Labor, Material, Site, Equipment, Transportation and Submittals are in the category of inputs, and Planning, Management, Coordination in the category of processes. The two main categories are used for identifying different solutions for the improvement of the PPP. In the following two sections, discussions will be given on how the main causes related to processes category are used for obtaining a list of prioritized opportunities for improvement, and how main causes related to inputs category are used for helping to identify and eliminate constraints from activities in order to make them ready for execution before they are included in the production plans.

5.2.1.4 Confirmed and prioritized opportunities for improvement

During the Define and Measure steps, potential areas for improvement in the PPP were identified. It was in Define step where the potential areas were firstly identified from the analysis of the information obtained in the First Stage and contained in the Organizational Structure, SIPOC Diagram, Flow Diagram and Project Charter. In the Measure step, results obtained from the measurement process helped to support or to disregard some of the potential areas identified. Therefore, in this Analysis step, after a more in-depth analysis assisted by the Pareto Chart, P-Chart and Cause and Effect Diagram tools, opportunities for improvement were confirmed and prioritized after a better understanding of the special and root causes behind the poor reliability of production plans.

Opportunity for improvement #1 – Change from traditional Push Planning System to Pull Planning System.

In the Define step, it was identified through the Flow Diagram tool that the original PPP in Project SB-T2 followed a traditional Push Planning System. It means that activities were programmed in the production plans mainly regarding what ***work should be done*** without having the certainty that ***can be done*** by means of the detection and elimination of their constraints. The consequences observed on site were the need for several amendments in the production plans after being analyzed in the 'General Coordination Meetings'. Moreover, in the Measure step the low levels of PPC and rolled PPC values and the variability in the Weekly PPC values evidenced the deficiencies in the original PPP. The deficiencies are largely related to unrealistic production plans which are unable to reflect the actual constraints of the construction environment and to control variability in the workflow. Finally in the Analysis step, it is appreciated that 'lack of continuity' was the Reason-NC of activities with higher frequency and among its main causes of poor planning, as shown in its Cause and Effect Diagram in Figure 5.11. Other main causes for poor 'Planning' include unrealistic production plans, inappropriate review process, errors and omission. Therefore, it was suggested that the characteristics of Pull Planning System, including the screening and pulling of activities and the workable backlog as introduced in Chapter 2, were appropriate for the improvement of PPP. This opportunity for improvement was prioritized as number #1. Priority #1 was given since this opportunity for improvement attempted to tackle problems related the most critical Reasons-NC (i.e. lack of continuity (10)) which are responsible for the poor reliability of production plans according to the measurements and analysis previously made.

Opportunity for improvement #2 – General Coordination Meetings

Coordination and communication between project team members is an opportunity for improvement that was not identified in the Define and Measure steps. However, in the Analysis step it was appreciated that the second and third most frequent Reasons-NC of activities (i.e. (3) and (8)) have the main causes Coordination, Management and Communication factors, as shown in Figure 5.11 and 5.12. It was acknowledged that many are the possible causes behind a poor coordination, poor management and bad communication. However, from the perspective of the PPP, an important potential opportunity for improvement was observed in the 'General Coordination Meetings': improving coordination and communication in the meetings. It is in these meetings where in Project SB-T2 the principal stakeholders involved in the activities to be executed meet to coordinate the work and take related decisions. Therefore it was appreciated that if the efficiency and effectiveness of these meetings was improved, such causes could be removed from the process.

Opportunity for improvement #3 – Revision and Approval of production plans

In the Define step, two potential areas for improvement were identified related to the revision and approval of production plans. One potential area was identified at the preliminary production plans level before the 'General Coordination Meeting', and another potential area was identified at the final production plans level just before their distribution. In the Measure step, problems in the revision and approval of production plans were also evidenced by the low PPC values registered during the First Stage. The problems indicate the inability of production plans to reflect the actual constraints of the construction environment even after several series of revision and approval stages in the PPP. Moreover, the Cause and Effect Diagram of Reasons-NC (3) and (8) as shown in Figures 5.11 and 5.12, evidenced 'Planning' as one of their main causes, and 'Planning' factors were identified including errors and omissions, inappropriate review process and poor document control. Therefore, the improvement of the approval and revision process in the PPP of Project SB-T2 is confirmed as an opportunity for improvement.

5.2.1.5 Definition of constraints to be used in Screening Activity Sheet (SAS)

After the series of analyses made in this Analysis step where the most frequent Reasons-NC with their respective main causes were identified, the 'screening constraints' to be used in the Screening Activity Sheet (SAS) were defined. Screening Activity Sheet (SAS) is a tool for screening all activities with the aim to eliminate their constraints before they are programmed for execution in the production plans. As introduced in Section 4.6.1, SAS defines its 'screening constraints' by performing an analysis of root causes related to the critical reasons for low reliability of productions plans. In this sense, the 'screening constraints' of SAS to be used for Project SB-T2 were defined based on the main causes identified in Section 5.2.1.3, including Labor, Materials, Site, Equipment, Transportation. Moreover, all factors under each main cause were used to formulate questions in order to facilitate the screening process. For instance, all factors under the main cause 'Materials' as presented in Figure 5.11 were transformed into questions for helping to screen activities and eliminate their constraints related to this main cause, as seen in Table 5.4. Same process was repeated for all main causes and SAS was built as seen in Appendix C.

Table 5.4 Screening questions for 'Materials' related constraints

Materials
Are 'materials' ready to be supplied?
Do 'materials' meet with the specifications?
Is it clear when and where 'materials' should be delivered?
Could 'materials' be delivered on time and in the place where they are needed?

5.2.2 Improve

Having completed the Define, Measure and Analysis steps of PLAN-SB implementation, the next step was to propose alternative processes for improving the PPP in Project SB-T2 according to the opportunities for improvement previously identified. Improvement measures were visually presented in an Improved PPP Flow Diagram as depicted in Figure 5.14. Moreover, production performance data and reasons for non-completion (Reasons-NC) of activities collected during the Second Stage were used for obtaining PPC values and Sigma Levels and consequently being able to verify if improvement was achieved after improvement actions.

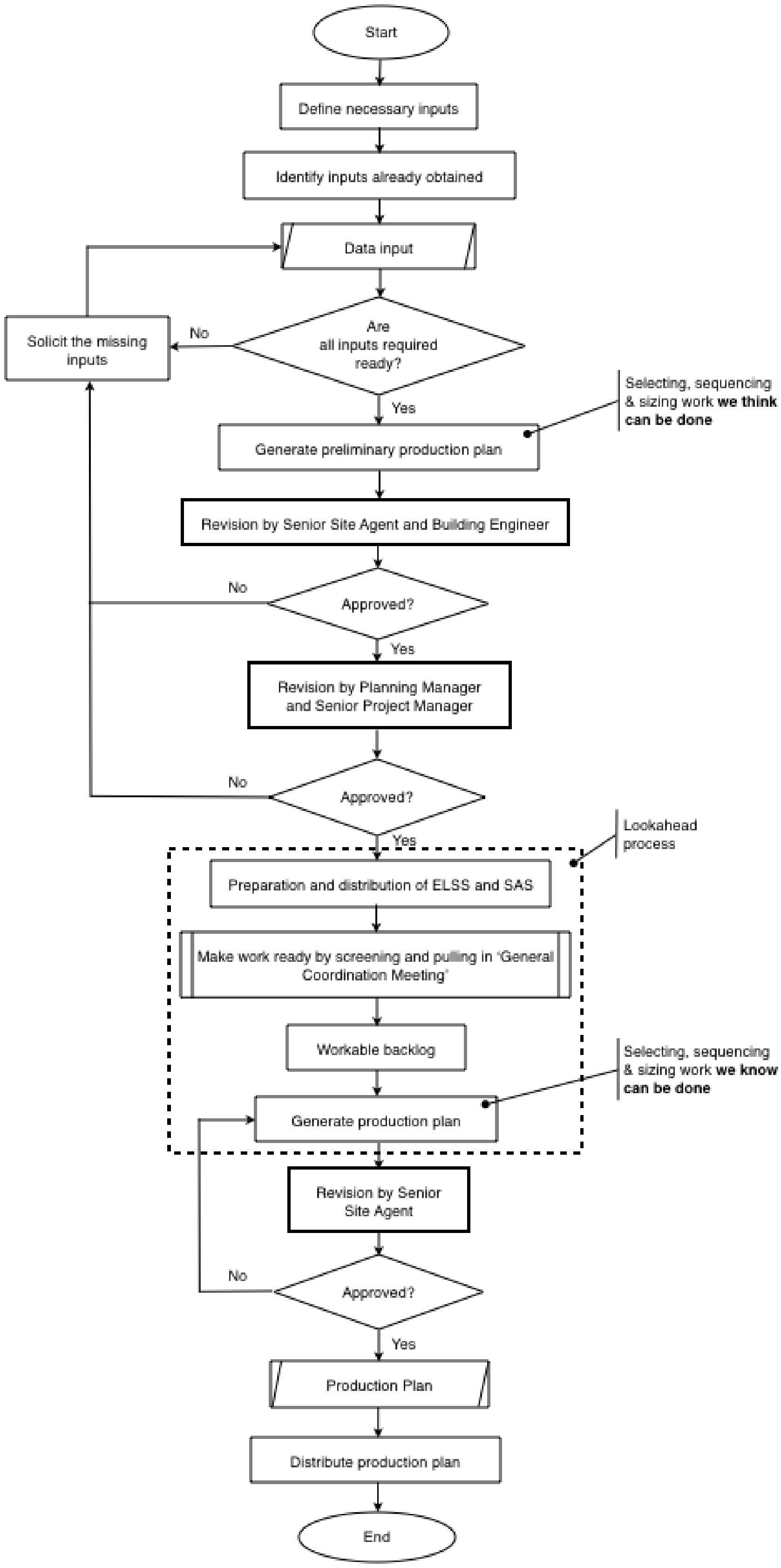


Figure 5.14 Improved PPP Flow Diagram

Main measures taken for improvement in the PPP

In Figure 5.14, the improvement measures are visually presented, including the change from Push Planning System to Pull Planning System, the first revision and approval stage of production plans, and the final revision and approval stage of production plans. These measures were taken by following the recommendations emerged from the analysis on the opportunities for improvement identified in previous stages of PLAN-SB implementation:

1. The first measure for improvement was related to the change from Push Planning System to Pull Planning System. This measure was taken by introducing the Lookahead process just after the second revision and approval of the preliminary production plans (as shown in Figure 5.14 and introduced in Chapter 2). In the original PPP, the preliminary production plans were simply submitted for revision to subcontractors in the 'General Coordination Meeting' for their approval and if approved these were distributed. The revision of production plans by the participants in the meeting did not follow formal procedures that could help them to analyze the plans or to communicate their particular needs for being able to execute the activities they were responsible.

   By introducing the Lookahead process, a more comprehensive revision and analysis of the preliminary production plans was made before and during the 'General Coordination Meeting'. Firstly, the Engineering Lookahead Schedule Sheet (ELSS), as introduced in Section 4.6.1, containing the preliminary production plan of 4 weeks time and the Screening Activity Sheet (SAS) were prepared for distribution one week in advance from the 'General Coordination Meeting'. ELSS and SAS were distributed to the project team members, subcontractors, consultants and suppliers who have relation to the activities to be analyzed. They were invited to analyze the preliminary production plans, propose modifications and raise outstanding needs if any related to the activities they were concerned. They were also invited to use SAS for screening all the activities they were responsible for, and for marking all constraints detected if any. Later, during the 'General Coordination Meeting' all participants were able to communicate their proposed modifications, outstanding needs and the constraints their future activities were attached to. During the meeting constraints were analyzed for their elimination and when possible eliminated. All activities free of constraints were identified and the production plan was jointly revised with the purpose to only program activities that were ready for execution. From the activities that are confirmed as free of constraints, a 'Workable backlog' was generated. It was from these activities that the production plans were generated by selecting, sequencing and sizing work, all parties knew can be done with higher certainty than before. By implementing the Lookahead process, it was expected to improve the reliability performance of production plans and reduce the problems caused by poor communication, coordination and management deficiencies previously reported.

2. The second measure for improvement was made regarding the importance prevailing in the first revision and approval stage of production plans. As identified in the Define step, it was in that stage where possible mistakes incurred by only the two planners with a limited experience could be identified. However, it was suspected that the 'Planning Manager'

responsible for that first revision and approval did not have all the necessary elements to accurately judge in such level of detail the quality of production plans because of his characteristic of off-site project team member. Therefore, a project team member with better knowledge of the project was considered more suitable for that responsibility, who should have proper knowledge of the current status of the project, construction site conditions, productivity rates, etc.

A second revision and approval stage was then more suitable for those project team members managing the project at a higher level such as the ‘Planning Manager’ who can take decisions based on other factors beyond facts or situations coming from the construction site. Therefore, the ‘Senior Site Agent’ and ‘Building Engineer’ replaced the ‘Planning Manager’ in the first revision and approval stage, and for the second one, the ‘Planning Manager’ replaced the ‘Senior Site Agent’. By taking these measures, it was expected to have more realistic preliminary production plans and make the Lookahead process more efficient by reducing the number of modifications

3. The third measure for improvement was made regarding the final revision and approval stage of production plans. From the original PPP, it was perceived that the single revision and approval by the ‘Senior Site Agent’ was a weak consensual final decision for making the production plans ready for distribution. However, by the introduction of a Lookahead process in PPP and the generation of a ‘Workable Backlog’ generated in consensus during the ‘General Coordination Meeting’, the final revision was considered less critical. Therefore, only if the ‘Senior Site Agent’

detected major problems, the production plan needs to be modified by replacing such activities causing problems with others contained in the 'Workable backlog'.

The measures for improvement introduced above were presented in and supported by means of an analysis report to the Senior Project Manager, Planning Manager and Senior Site Agent for their revision and approval. Measures were approved with only one minor modification, which is that ELSS and SAS should be prepared and distributed 3 workable days before the 'General Coordination Meeting' instead of one week as proposed. It was argued that one week was too much time in advance for ELSS and SAS to be delivered due to the fact that project team members could forget to make the analysis and fill the sheets. Therefore 3 days was regarded as more appropriated. Thus, the improvement measures were implemented and this process took place from Week 6 to Week 10. During that time, production performance data and the Reasons-NC were recorded from all activities planned in order to calculate the PPC and rolled PPC values, Sigma Levels and identify possible changes in the frequency of Reasons-NC after improvement measures in the PPP.

5.2.2.1 PPC vs. rolled PPC Analysis after applying improved PPP

Having applied the improved PPP, the PPC and rolled PPC metrics were used for verifying if improvement was achieved. In line with this, data collected from Week 6 to Week 10 was used to calculate the daily PPC, Weekly PPC and rolled PPC values. This data was later used to plot a graph of Weekly PPC vs. rolled PPC for Tower 1 and Tower 2 as seen in Figure 5.15 and 5.16 respectively for further analysis.

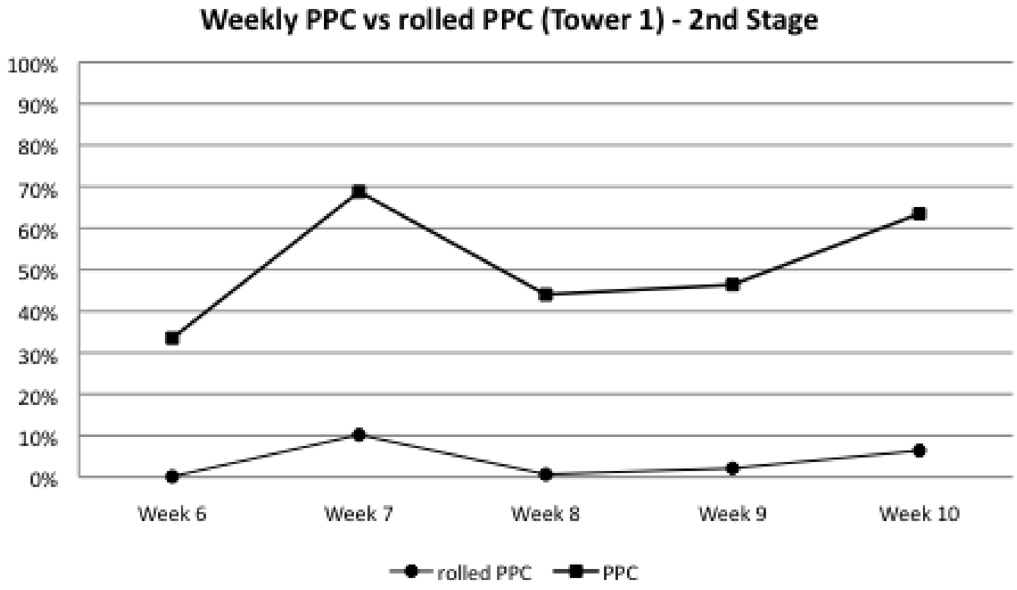


Figure 5.15 Weekly PPC vs. rolled PPC (Tower 1) – 2nd Stage

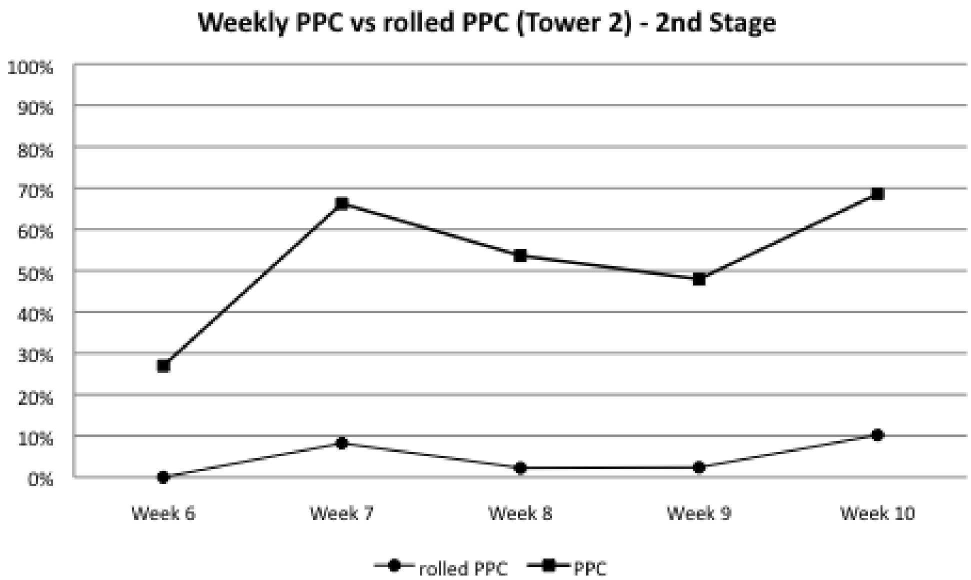


Figure 5.16 Weekly PPC vs. rolled PPC (Tower 2) – 2nd Stage

From the graphs it is appreciated that a more similar performance between Tower 1 and Tower 2 was achieved in comparing to the First Stage performances. In fact, both Towers reached a very similar average PPC during the Second Stage, Tower 1 reaching an average PPC of 51.23% while Tower 2 reached 52.69% and both reaching the same maximum Weekly PPC value of 68%. However, an important difference existed in the variability between the two towers. Weekly PPC values in Tower 2 varied in a higher range with a difference of 41.62% between its highest and its lowest values (68.59% - 26.97), while in Tower 1 this difference was only of 35.31% (68.80% - 33.49%). This variability in both Towers could suggest a low reliability in the production plans even after the improvement measures in the PPP. However, it should be noticed that the first production plan generated by the improved PPP was not obtained until Week 7 when the first 'General Coordination Meeting' was held in the Second Stage period. Therefore, activities during Week 6 were planned under the original PPP. Thus, if variability is measured only during the period between Week 7 and Week 10 much lower difference would be recorded between their highest and lowest PPC values. In fact, Tower 1 registered a variability of 24.81%, while Tower 2 registered a variability of 20.63%.

It is interesting to notice that the highest positive variations in the Weekly PPC in both towers were obtained precisely in the week when the first production plans generated by using the improved PPP were adopted (i.e. in Week 7). This fact suggested that production plans obtained from the improved PPP were more reliable. However, it was also acknowledged that more resources were assigned to both Towers during the Second Stage, especially to Tower 2 which was experiencing low production performance due to priority given to Tower 1 during the First Stage. Therefore, it is also suggested that because more resources were assigned, more activities were able to meet their due times as scheduled. For understanding in what degree the improvement in PPC values were due to the improvement measures taken in the PPP, a further analysis is made in the following sections.

5.2.2.2 Calculation of Sigma Level after applying improved PPP

It is the purpose of this section to use the properties of Sigma Levels for corroborating improvement after the application of the improved PPP. Sigma Levels have the properties of communicating the overall performance of the PPP in a single value and, as a normalized value, can be used for benchmarking the PPP performance before and after its improvements. Therefore, once the PPC values during the Second Stage period were obtained for both Towers, their corresponding Sigma Levels were also calculated and are presented as follows:

Sigma Level for Tower 1: **2.67 σ**

Sigma Level for Tower 2: **2.68 σ**

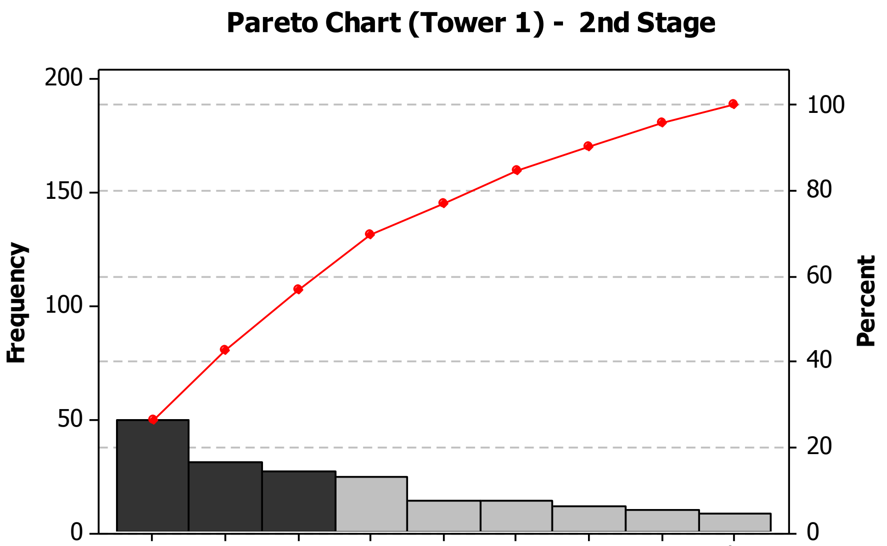
It is appreciated that Sigma Levels accurately reflected the similarities in performance between the two towers as previously suggested by the PPC values. This fact manifested once again the appropriateness of using Sigma Levels for benchmarking the performance of the PPP before and after improvement measures. Therefore, Sigma Levels obtained during Second Stage were benchmarked with those obtained during the First Stage. From the benchmarking, improvement in the PPP was evidenced in both Towers. Such improvement was especially significant in Tower 2, having a difference of .48σ (2.68σ -2.20σ).

Tower 1 also experienced an improvement, however, it was only of .13σ (2.67σ - 2.54σ). Therefore, the reasons behind such important difference in improvements between Tower 1 and Tower 2 were further explored in the following sections with assistance of Pareto Chart and P-Chart tools.

5.2.2.3 Pareto Chart analysis of Reasons-NC after applying improved PPP

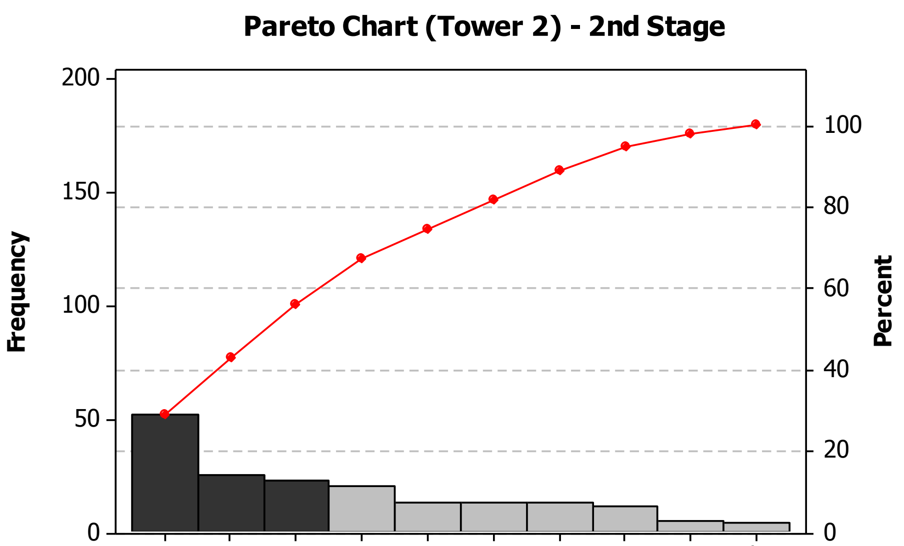
After the improvement of the PPP, it was relevant to identify possible decrements in the frequency of Reasons-NC after the improvement of PPP and to explore what Reasons-NC were attributed the majority of activities incomplete during the Second Stage. Relevant changes in the frequencies of Reasons-NC were further investigated in order to determine if these changes of frequencies were caused or related to the effects of the improved PPP.

For enabling such analyses, the Reasons-NC of activities were recorded from 05-May to 08-June, corresponding to the Second Stage period, and plotted in Pareto Charts for the analysis purposes. Figures 5.17 and 5.18 illustrate the Pareto Charts derived from the data obtained in Tower 1 and Tower 2 respectively.



Reason-NC ID	10	8	2	3	7	11	1	4	Other
Frequency	49	31	27	24	14	14	11	10	8
Percent	26.1	16.5	14.4	12.8	7.4	7.4	5.9	5.3	4.3
Cum %	26.1	42.6	56.9	69.7	77.1	84.6	90.4	95.7	100.0

Figure 5.17 Pareto Chart of reasons for non-completion (Tower 1) – 2nd Stage



Reason-NC ID	10	2	3	8	1	7	11	4	6	Other
Frequency	52	25	23	20	13	13	13	11	5	4
Percent	29.1	14.0	12.8	11.2	7.3	7.3	7.3	6.1	2.8	2.2
Cum %	29.1	43.0	55.9	67.0	74.3	81.6	88.8	95.0	97.8	100.0

Figure 5.18 Pareto Chart of reasons for non-completion (Tower 2) – 2nd Stage

From Figures 5.18 and 5.18, it is observed that the cumulative of 84.6% of all Reasons-NC recorded during the Second Stage in Tower 1 were concentrated in 6 Reasons-NC. Similarly, in Tower 2 the cumulative of 81.6% was concentrated in 6 Reasons-NC. Therefore, both Towers did not comply with the ‘80/20’ rule this time as they did in the First Stage, since 6 out of 13 reasons represent a 46.15% instead of a 20% needed. In other words, in order to have a greater impact in the improvement process during the following stage, improvement should be sought by eliminating 6 Reasons-NC instead of 3 and 4 as resulted for Tower 1 and Tower 2 respectively during the first stage. However, having such results does not mean they were negative ones, since they were mainly attributed to an important decrement in the frequency recorded by Reasons-NC (10) and (3) in Tower 1 and (10) and (8) in Tower 2.

Increments in frequencies were also reported during the Second Stage and the most important one was in Reason-NC (2) in both Towers. In Tower 1, Reason-NC (2) increment was of 9.3% (14.4% - 5.1%), while in Tower 2 the increment recorded was of 4.3% (14.0% - 9.7%). Possible causes behind the changes in frequency of Reasons-NC between First Stage and Second Stage periods were explored by means of a more in-depth analysis of daily PPC values and the use P-Chart tools as presented in the following two sections.

5.2.2.4 P-Chart analysis after applying improved PPP

In previous sections, it has been by the use of PPC values, the Sigma Levels and Pareto charts that evidence of improvement has been found during the Second Stage period of PLAN-SB implementation. PPC values and Sigma Levels increased, while reasons for non-completion (Reasons-NC) and variability in the workflow decreased. Whilst these improvements could be associated with the application of the improved PPP, such assumption had to be verified. In this sense, the properties of the P-Chart tool can help to make a more in-depth analysis for better understanding and explaining the causes behind the improvements achieved. Therefore, daily PPIC values obtained during the Second Stage period (i.e. from 5-May to 8-Jun) were plotted in P-Charts for Tower 1 and Tower 2 as shown in Figures 5.19 and 5.20 respectively. Vertical dashed lines were added to the P-Charts in order to indicate the day when ‘General Coordination Meetings’ were held. Since it was in these meetings where production plans were approved and then applied, it was considered important to highlight the performance of PPIC values from one meeting to another in order to make individual analysis to each production plan. Three types of analysis were made to the P-Charts, namely overall flow analysis, test analysis and general variations analysis presented as follows:

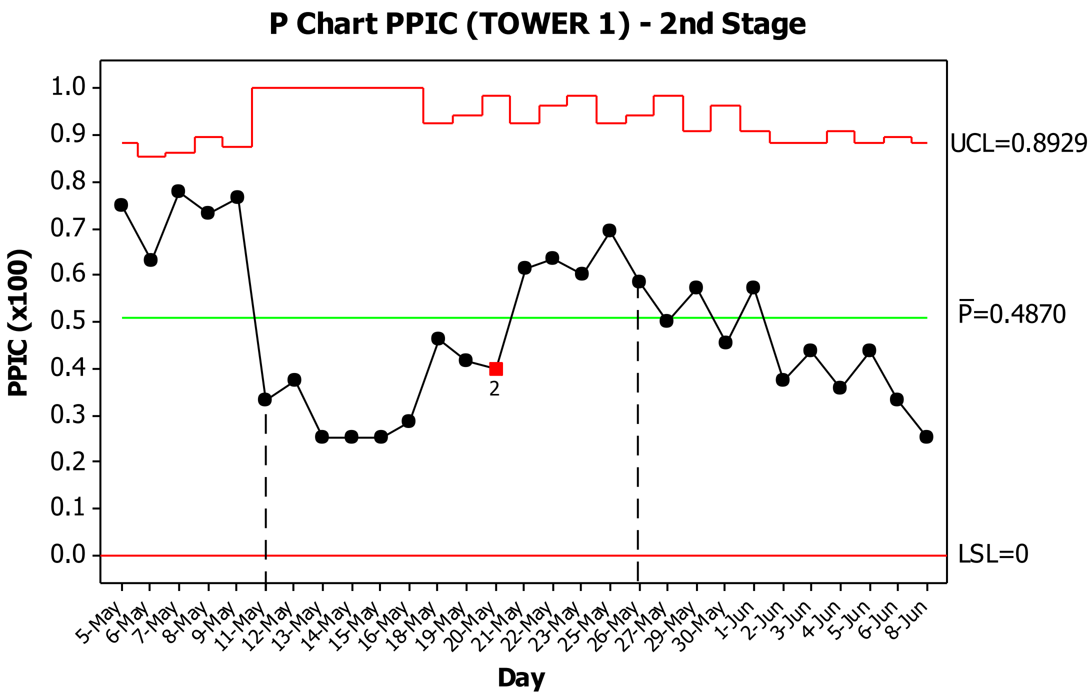


Figure 5.19 P-Chart PPIC (Tower 1) – 2nd Stage

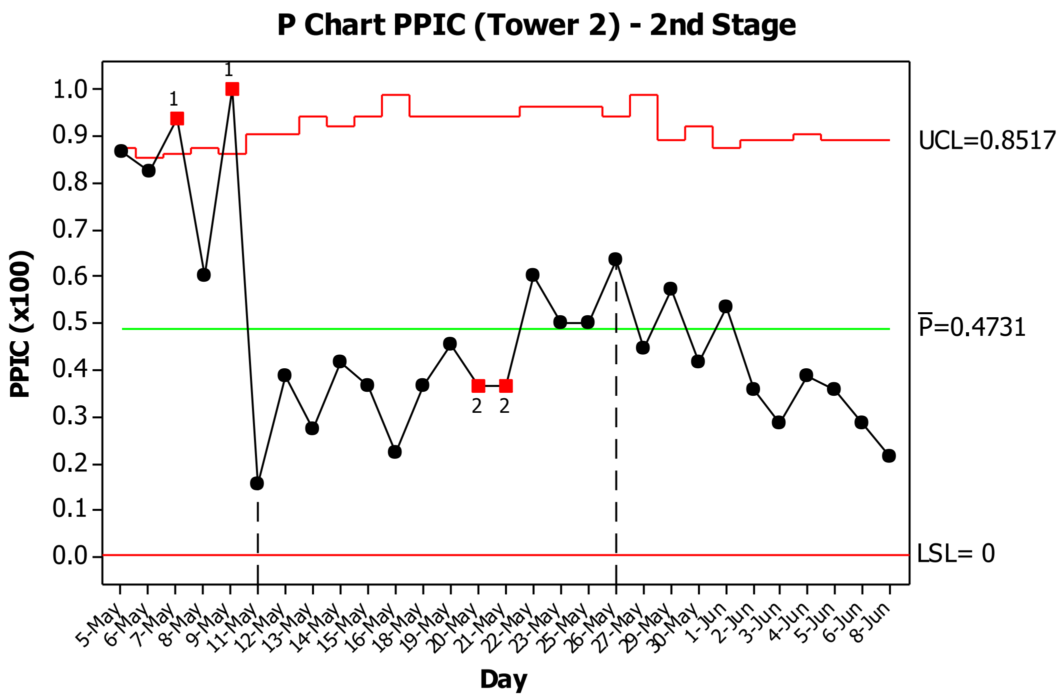


Figure 5.20 P-Chart PPIC (Tower 2) – 2nd Stage

Overall Flow Analysis

From Figures 5.19 and 5.20, it is appreciated that more variability existed in Tower 2 than in Tower 1 with a difference in Tower 2 of 84.62% between its highest and its lowest (100% - 15.38%), while in Tower 1 this difference was only of 52.78 (77.78% - 25%). These variability values are even higher than the ones registered in the First Stage and could have suggested a lower reliability in the production plans even after the improvement measures in PPP.

However, as noticed before, production plans generated by the improved PPP were not applied until Week 7, more specifically until 11-May when the first 'General Coordination Meeting' was held in the Second Stage period. Therefore, if variability is measured only during the period between 11-May and 8-June much lower variability values are registered. In fact, Tower 1 registered a variability of 44.23%, while Tower 2 registered a variability of 48.26%. Thus, such reduction in variability implied a higher reliability of production plans generated from the improved PPP.

Test Analysis

Figure 5.19 shows that a special variation is evidenced. This special variation is related to an improvement trend of PPIC values which was maintained for at least 9 consecutive times under CL (i.e. Test #2). It can be seen from Figure 5.19 that the improvement started in the transition between Week 6 (5-May to 11-May) and Week 7 (12-May to 18-May). Therefore, it was relevant to identify the main frequency reductions of Reasons-NC between these two weeks for determining what triggered such improvement. By examining the compilation of Reasons-NC in the Second Stage contained in Appendix B, it was found that from Week 6 to Week 7 the main frequency reductions were in Reasons-NC (3), (8), (10) and (2).

In Figure 5.20, two different tests also evidenced special causes. Test #1 evidenced two PPIC values crossing the UCL. Since both signal tests #1 occurred during Week 6, Reasons-NC during this week were examined in order to identify the special causes that could have generated such bad performance. In this process, it was found that two Reasons-NC which were not manifested during the First Stage period were present in Week 6. The two Reasons-NC were Reasons-NC (6) representing 'Changes/redoing work (design errors)' and Reasons-NC (7) representing 'Changes/redoing work (site errors)'. And, the specific activities reporting these Reasons-NC were: 'Air Conditioning & Electrical/Mechanical plumbing installation from floors 8 to 33' and 'Lift planning and installation inside lift shaft from floor 50 to Roof'. Both activities experienced some clashes originated from design errors, which provoked some necessary reworks.

In Tower 2, another signal test was triggered related to an improvement of PPIC values. Such improvement was registered just as in Tower 1, between Week 6 and Week 7. By examining the main frequency reductions of Reasons-NC between these two weeks, it was found that reduction in Reasons-NC (3), (10), (6) and (7) could have generated such improvement.

General Variations Analysis

1. It is appreciated that in both Towers an important reduction in PPIC values was recorded just after the second 'General Coordination Meeting' during the second stage. Even though the reduction tendency in PPIC values did not triggered the signal test #3 (i.e. 6 consecutive PPIC values all increasing or decreasing), the tendency achieved a reduction of 33.33% and 42.21% in Tower 1 and Tower 2 respectively. Since both reductions tendencies started after the 'General Coordination Meeting', it implied that such improvements are also related to the higher reliability of production plans generated from the improved PPP.

5.2.2.5 Analysis on Production Plans Performance for verifying effects of improved PPP

The discussion in the previous section demonstrates the improvements related to the reduction of PPIC values and reduction of variability after 'General Coordination Meetings'. The main frequency increments and decrements of Reasons-NC related to these improvements were also identified. Consequently, it is relevant to explore in what extent the improved PPP helped to eliminate constraints related to the frequency reductions of Reasons-NC contributing to these improvements. Such analysis is made by comparing the highest frequency reductions of Reasons-NC with the constraints eliminated in the ‘General Coordination Meetings’ following the improved PPP. Therefore, if a positive relation exists, the improvements generated by the reduction of frequencies of Reasons-NC can be attributed to the improved PPP.

For the purpose of this analysis two tables were generated. Table 5.5 was generated to show the main frequency increments/decrements of Reasons-NC registered between the periods under analysis. And, Table 5.6 was generated to show the constraints detected and eliminated in the Lookahead process during the ‘General Coordination Meetings’ of the improved PPP and their relation with Reasons-NC.

Table 5.5 Frequency increments/decrements of Reasons-NC (Second Stage)

Reasons-NC ID		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Tower 1														
Frequency	Week 5 – Week 6	3	8	21	0	0	4	4	21	0	34	6	0	1
	Week 7 – Week 8	6	8	2	4	0	0	6	10	3	13	4	0	0
Difference		3	0	**19**	4	0	4	2	**11**	3	**21**	2	0	1
Increment (↑) Decrement (↓)		↑	=	↓	↑	=	↓	↑	↓	↑	↓	↓	=	↓
Frequency	Week 7 – Week 8	6	8	2	4	0	0	6	10	3	13	4	0	0
	Week 9 – Week 10	2	13	9	6	0	0	4	9	0	20	4	0	0
Difference		**4**	**5**	**7**	2	0	0	2	1	3	**7**	0	0	0
Increment (↑) Decrement (↓)		↓	↑	↑	↑	=	=	↓	↓	↓	↑	=	=	=
Tower 2														
Frequency	Week 5 – Week 6	5	13	19	1	0	5	6	20	0	33	8	0	2
	Week 7 – Week 8	7	9	4	4	0	0	3	8	2	13	2	0	0
Difference		2	4	**15**	3	0	5	3	**12**	2	**20**	6	0	2
Increment (↑) Decrement (↓)		↑	↓	↓	↑	=	↓	↓	↓	↑	↓	↓	=	↓
Frequency	Week 7 – Week 8	7	9	4	4	0	0	3	8	2	13	2	0	0
	Week 9 – Week 10	1	9	8	6	0	0	4	4	0	22	4	0	0
Difference		**6**	0	**4**	2	0	0	1	**4**	2	**9**	2	0	0
Increment (↑) Decrement (↓)		↓	=	↑	↑	=	=	↑	↓	↓	↑	↑	=	=

Table 5.6 Constraints eliminated in Second Stage

Screening constraint	Change Order/Priority	Design	Materials	Labor	Equipment	Prerequisite work	Submittals	Transportation	Space
Reason-NC relation	(8)	(6) (7)	(1)(2)	(3)	(3) (5)	(10)	(9)	(1) (3) (11)	(4) (11)
First Meeting (11-May)									
Tower 1	7	1	3	14	2	18	0	1	0
Tower 2	13	1	3	12	3	19	0	2	2
Total	20	2	6	26	5	37	0	3	2
Second Meeting (26-May)									
Tower 1	6	1	3	3	1	11	0	2	1
Tower 2	7	1	5	7	2	13	0	2	0
Total	13	2	8	10	3	23	0	4	1

Production plan for Week7-Week8 analysis

Production plan for Week7 to Week 8 was the first one produced by the improved PPP and its analysis included a comparison between the periods Week5-Week6 and Week7-Week8. These periods were selected for analyzing the relations between frequency reductions of Reasons-NC and constraints eliminated in the first 'General Coordination Meeting' held on 11-May in which the improved production plan was generated. Table 5.7 presents the Reasons-NC with highest frequency decrements between Week5-Week6 and Week7-Week8 periods. The data in the table also presents the most constraints eliminated for Week7-Week8 period.

Table 5.7 Comparative information for Week7-Week 8 production plan analysis

Tower	Highest frequency decrements: Reason-NC ID	Highest frequency decrements: Decrement	Most Constraints eliminated: Reason-NC ID relation	Most Constraints eliminated: Eliminated
Tower 1	(10)	21	(10)	18
	(3)	19	(3)	14
	(8)	11	(8)	7
Tower 2	(10)	20	(10)	19
	(3)	15	(3)	12
	(8)	12	(8)	13

From the information above it is appreciated that Reasons-NC (10), (3) and (8) represented the reasons with the highest reductions in frequency from Week5-Week6 to Week7-Week8 periods in both Towers. Moreover, reasons related to constraints eliminated from activities during the period Week7-Week8 were exactly the same as those reporting the highest frequency decrements. This implies that the elimination of constraints achieved in the improved PPP provoked the reduction of frequencies of Reasons-NC (10), (3) and (8), which in turn lead to the improvements related to the reduction of PPIC values and reduction of variability.

Between these two periods, it is also observed that some Reasons-NC incremented their frequencies. They were reasons (4), (1) and (9). This was a very useful signal that was used to focus or put more attention on constraints related to these reasons in the next Lookahead process.

Production plan for Week9-Week10 analysis

Production plan for Week9-Week10 period was generated on 26-May. For analysis, a comparison between the periods Week7-Week8 and Week9-Week10 was needed. Table 5.8 presents the Reasons-NC with highest frequency decrements/increments between Week7-Week8 and Week9-Week10 periods. The data in the table also presents the most constraints eliminated for Week9-Week10 period.

Table 5.8 Comparative information for Week9-Week10 production plan analysis

Tower 1

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(1)	4	(10)	11
(9)	3	(8)	6
(7)	2	(1)	5
(8)	1	(3)	3

Higher frequency increments

(10)	7
(3)	7
(2)	5

Tower 2

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(1)	6	(10)	13
(8)	4	(3)	7
(9)	2	(8)	7
		(1), (2)	5

Highest frequency increments

(10)	9
(3)	4
(11)	2
(4)	2

From the information presented above it is appreciated that during Week9-Week10 period most constraints eliminated did not have much relation with the Reasons-NC with highest frequency decrements. In fact only Reasons-NC (8) and (1) were related and this occurred in both Towers. It is also appreciated that the Reasons-NC with highest frequency decrements in the previous analysis (i.e. (10)

and (3)), in contrast, were the ones with highest frequency increments in this period. In fact, it is appreciated that the number of constraints eliminated related Reasons-NC (10) and (3) in Week9-Week10 period were lower than the ones eliminated in the previous one. Therefore, the high PPIC values reached during Week9-Week10 period as appreciated in Figures 5.19 and 5.20 are associated to the inability to detect and eliminate constraints related to Reasons-NC (10) and (3). Consequently, the report of highest frequency increments rightly sent a signal for putting more attention to constraints related to this Reasons-NC.

5.3 Third Stage (Control)

5.3.1Control

The aim of this section is to demonstrate if the improvements achieved during the Second Stage were maintained in the Third Stage of PLAN-SB implementation and to compare the achievements gauged between these two Stages. As appreciated in the Second Stage, improvements were not well maintained during the second stage, which indicates that there is still important variability present in the workflow. Therefore, the analysis in this section focused on exploring in what extent the improvement was controlled by the improved PPP during the Third Stage and whether there was a continuous improvement. Similarly as in previous stages, PPC and Sigma Level metrics and Pareto Charts and P-Charts tools were used as basis for the analysis on the improvement of performance in the Third Stage

5.3.1.1 Control analysis on PPC and rolled PPC values

In order to verify if the improvements achieved during the Second Stage were maintained and controlled in the following weeks during the Third Stage, data collected from Week 11 to Week 17 corresponding to the Third Stage was used to calculate the daily PPC, Weekly PPC and rolled PPC values. These values were used to plot a graph of Weekly PPC vs. rolled PPC for Tower 1 and Tower 2 respectively for the analysis purposes. The graphs are presented in Figures 5.21 and 5.22.

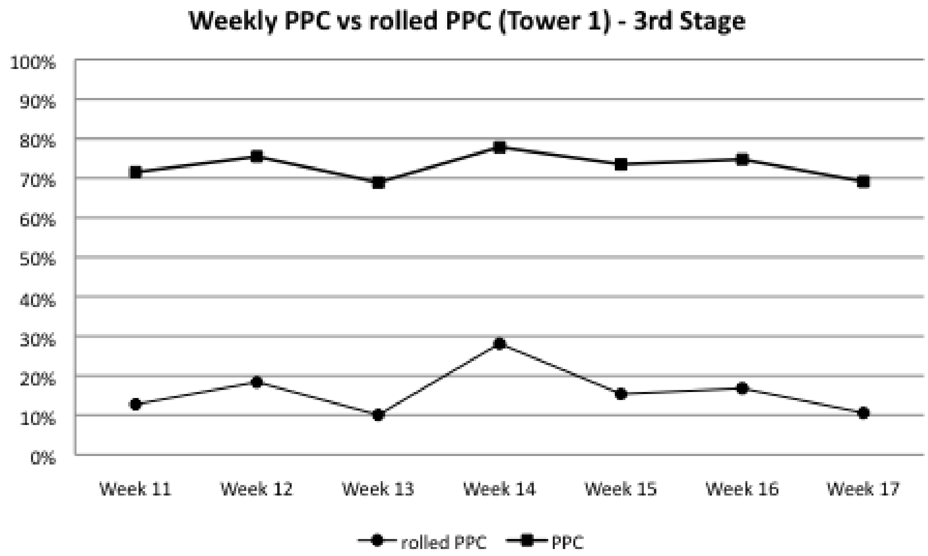


Figure 5.21 Weekly PPC vs rolled PPC (Tower 1) – 3rd Stage

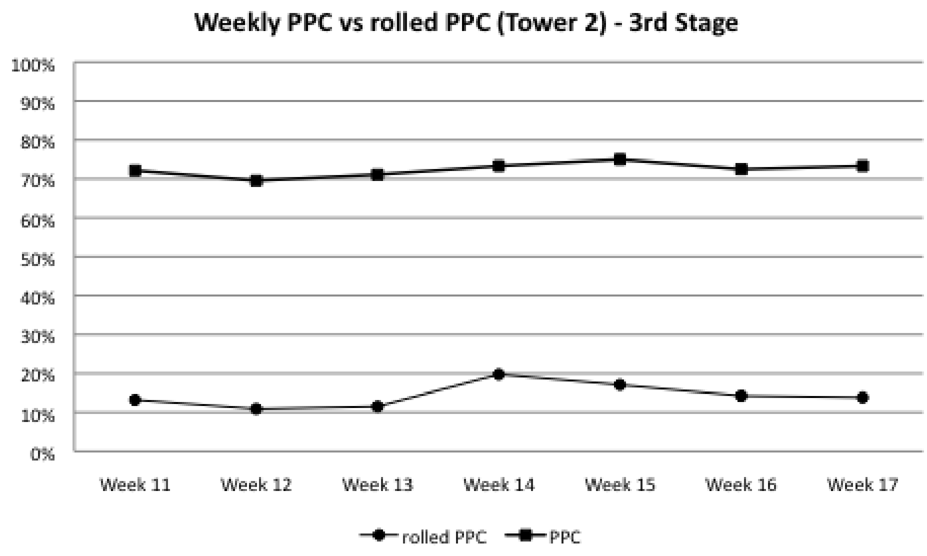


Figure 5.22 Weekly PPC vs rolled PPC (Tower 1) – 3rd Stage

From Figures 5.21 and 5.22 it is appreciated the constant achievement of high PPC values during the Third Stage leading to an average PPC of 73.03% and 72.43% in Tower 1 and Tower 2 respectively. In fact, it is noticed that in the Second Stage, PPC values started with the lowest value in the first week and finished with the highest in the last week. In the Third Stage, it is noticed that the first week already achieved a high PPC value, which could be attributed to the good tendency of improvements achieved in the Second Stage.

From the figures it is also observed the low variability in the workflow achieved in the Third Stage in both Towers. For instance, the variability registered in Tower 1 was only of 8.94% (77.686% - 68.92%) and in Tower 2 was of 5.46% (75.00% - 69.54%). Rolled PPC values also presented important increments compared with the previous stages. This means that more work was finished not only in the week it was planned but also in the day it was planned. It is interesting to observe that the highest rolled PPC value achieved in this stage was recorded in

Week 14 in both Towers, therefore in the P-Chart analysis section a more in-depth analysis was made for identifying the causes behind this improvement.

5.3.1.2 Overall analysis and benchmarking of Sigma Levels during PLAN-SB implementation

In the previous two stages Sigma Levels have helped to benchmark the PPP performance and give a general reference of where and when a good performance was achieved. In the Third Stage, Sigma Level is used with the purpose to indicate where and when improvements in the PPP performance were achieved among the 3 different stages and between the two towers. From the PPC values obtained in both Towers during the Third Stage, Sigma Levels were calculated and are presented as follows:

Sigma Level for Tower 1: **3.11 σ**

Sigma Level for Tower 2: **3.10 σ**

From the Sigma Levels presented above, the first thing noted is that the difference in performance between the two towers in the Third Stage was minimum. Such similitude in the two values demonstrates a controlled PPP performance between the two towers and how it has been well maintained and improved from the Second Stage. In fact, if Sigma Levels obtained in the Second Stage are compared with the ones obtained in the Third Stage, it is observed that improvements were of similar value in the two towers. Tower 1 obtained an improvement of 0.44σ and Tower 2 of 0.42σ.

Now, if Sigma Levels from the First Stage to the Third stage are compared, it is noticeable the great improvement in the PPP performance achieved over the three stages of PLAN-SB implementation. Tower 1 reported an improvement of .57σ (3.11σ -2.54σ) and Tower 2 of .90σ (3.10σ - 2.20σ). Therefore, it is observed that Tower 2 had the most important improvement derived from the implementation of PLAN-SB and its highest improvement was reported from First Stage to Second Stage.

Although important improvements were achieved in the PPP performance in Project SB-T2, its highest Sigma Level of 3.11σ is still average in comparing to other industries according to the sigma levels scale proposed by Harry and Schroeder (2006). However, it should be recognized that high Sigma levels in Construction Industry related processes would be very difficult to achieve because of the uniqueness nature of its projects generating high number of uncertainties as previously argued by others (Basu 2009; Linderman et al. 2003). For instance, other studies have demonstrated similar or even lower Sigma Levels in construction processes placed them in the 'Industry Average' or 'Non-competitive' level, such as the one related to internal finishing works in public housing projects in Singapore with a 2.66σ (Stewart and Spencer 2006) and to the assembling process in a construction project building power transmission lines with a 1.41σ (Pheng and Hui 2004).

5.3.1.3 Reasons-NC analysis over the implementation of PLAN-SB

After the completion of the Third Stage, it was possible to identify which Reasons-NC decreased their frequencies in a higher extent during the implementation of PLAN-SB. As appreciated in previous sections, by the use of Pareto Charts, the Reasons-NC with the highest frequency in Project SB-T2 were identified in the previous two stages. Similarly, with the Reasons-NC recorded in the Third Stage (from 9-Jun to 27-July), Pareto Charts were plotted for each Tower as seen in Figures 5.23 and 5.24 respectively. The Pareto Charts were later used for identifying the Reasons-NC that caused more incomplete activities during the Third Stage and be able to compare them with data obtained in the previous two stages.

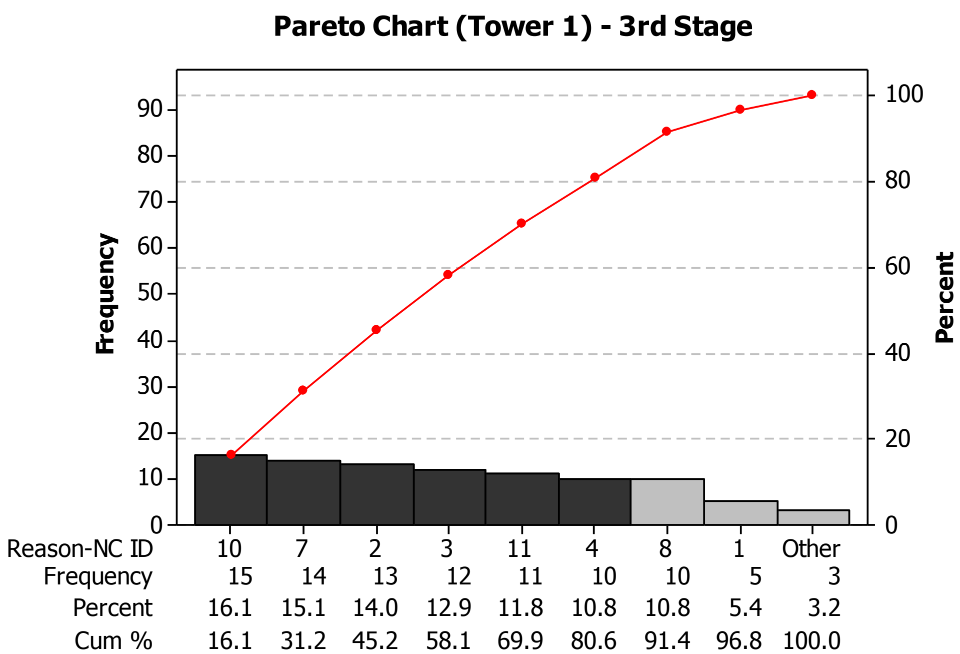


Figure 5.23 Pareto Chart of reasons for non-completion (Tower 1) – 3rd Stage

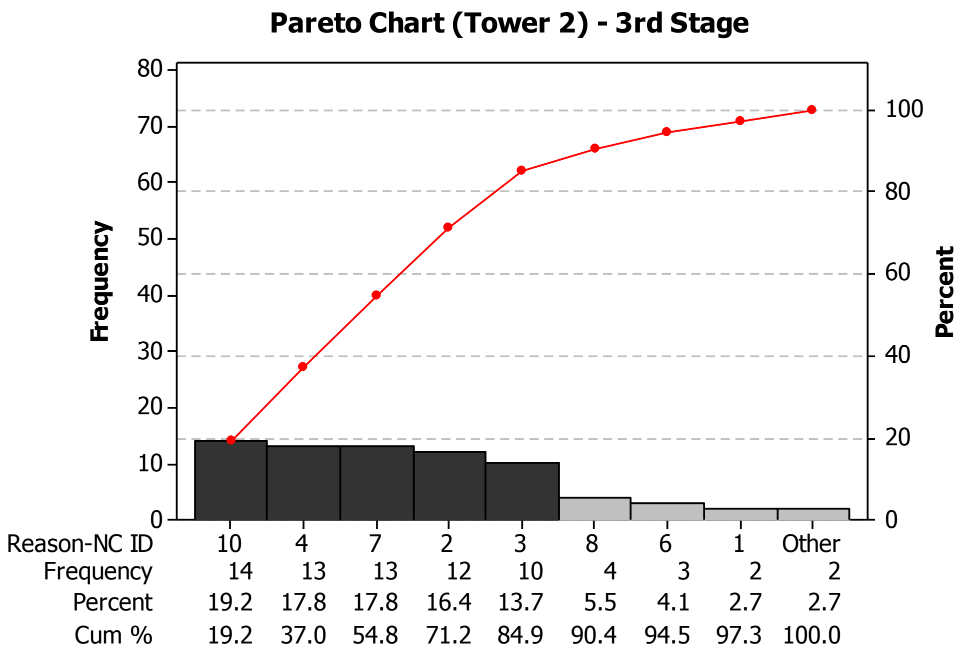


Figure 5.24 Pareto Chart of reasons for non-completion (Tower 2) – 3rd Stage

From the above Figures it is appreciated that in the Third Stage, Reasons-NC (7) (i.e. 'Changes/redoing work (site errors)) became the second and third more frequent Reason-NC in Tower 1 and Tower 2 respectively. However, its frequency did not change from the Second Stage to the Third Stage. Therefore, the reason why it became the second more frequent Reason-NC is because other Reasons-NC such as Reasons-NC (8) and (3) had frequency decrements. Aspects related to Reason-NC- (7) such as rework related to site errors cannot be easily detected or predicted as a constraint when planning activities for execution, since there is not single root cause for such errors. As the root causes of the Reason-NC (7) cannot be detected, the Lookahead process in the improved PPP cannot effectively help to reduce this Reason-NC. Similarly, 'Lack of access' related to Reason-NC (4) became the second more frequent in Tower 2. In fact, its increment from Second Stage to Third Stage is quite low, but as the previous case, other Reasons-NC reduced their frequencies.

It is appreciated that in general most Reasons-NC were reducing their frequencies over the three Stages. For better illustrating such tendencies, Table 5.9 was prepared in order to show the decrement rates of the most frequent Reasons-NC reported in the First Stage (i.e. Reasons-NC (10), (8) and (3)). For instance, from Table 5.9 it is appreciated that Reason-NC (10) achieved the greatest decrements in frequency in both towers. In Tower 1 going from a frequency of 97 to 15 and in Tower 2 from 103 to 14. Furthermore, it is interesting to notice that Reason-NC (8) related to incomplete activities for ‘moving to other work areas’ was more frequent in Tower 2 than in Tower 1 during the First Stage. However, in the Second Stage Reason-NC (8) was more frequent in Tower 1. This is attributed to the change in work priority from Tower 1 to Tower 2 in the Second Stage. More efforts were contributed to Tower 2 in the Second Stage due to bad production performance reported in Tower 2 during the First Stage.

In general, it is appreciated a great decrement of frequency of these and other reasons over the three stages, and these decrements enabled the achievement of higher values of PPC, as highlighted in Figures 5.21 and 5.22. However, whether the these decrements were related to the improvement measures taken in the improved PPP for producing more reliable production plans should be analyzed. The analysis of the relation between the Reasons-NC decrements in frequency with the elimination of constraints during implementing the improved PPP will be presented in next sections.

Table 5.9 Decrement rate of reasons for non-completion

	First Stage		Second Stage		Third Stage
Tower 1					
Frequency of reason (10)	97		49		15
Decrement rate		50.52%		30.61%	
Frequency of reason (8)	45		31		10
Decrement rate		68.89%		32.26%	
Frequency of reason (3)	50		24		12
Decrement rate		48.00%		50.00%	
Tower 2					
Frequency of reason (10)	103		52		14
Decrement rate		50.49%		26.92%	
Frequency of reason (8)	59		20		4
Decrement rate		33.90%		20.00%	
Frequency of reason (3)	37		23		10
Decrement rate		62.16%		43.48%	

5.3.1.4 P-Chart Analysis

From the previous analyses made to the PPP performance during the Third Stage period, it is appreciated that important improvements have been achieved in both important indicators: the reliability in the workflow and the weekly and daily PPC values. In this section through the use of the P-Chart tool, it is verified if improvements attained in the Second Stage were maintained during the Third Stage. The analysis will also be given to when the most important improvements were achieved and what caused such improvements. Figures 5.25 and 5.26 demonstrate the P-Charts of Tower 1 and Tower 2 respectively. The charts were plotted using the PPIC values obtained during the Third Stage period (i.e. from 9-June to 27-July).

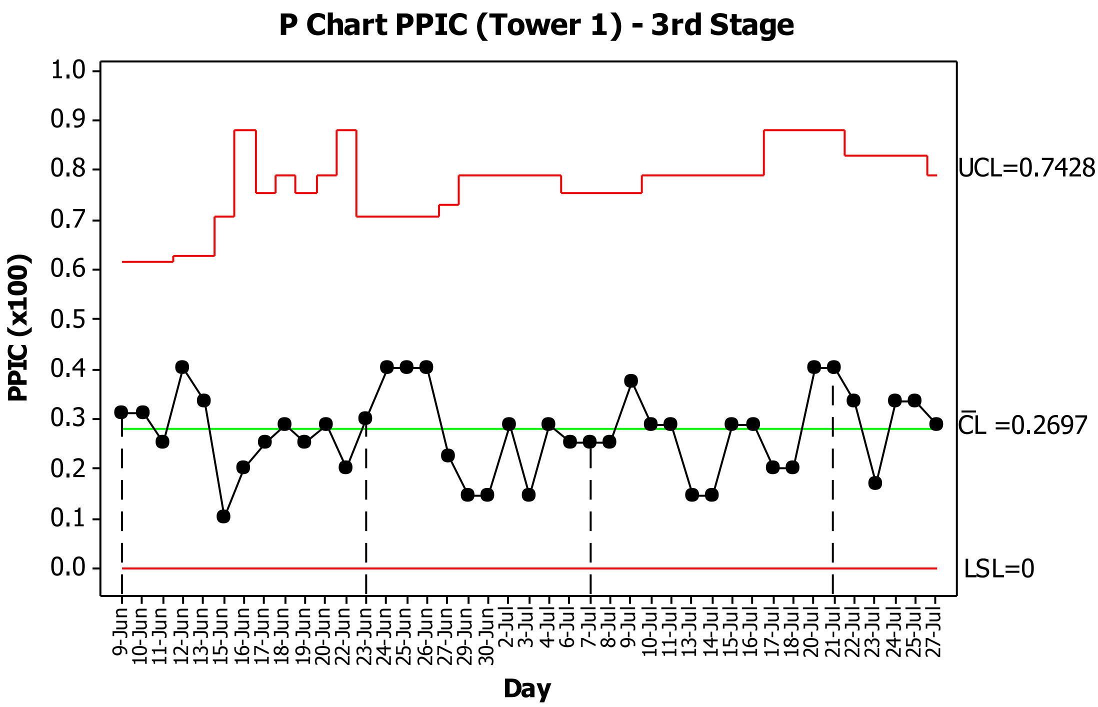


Figure 5.25 P-Chart PPIC (Tower 1) – 3rd Stage

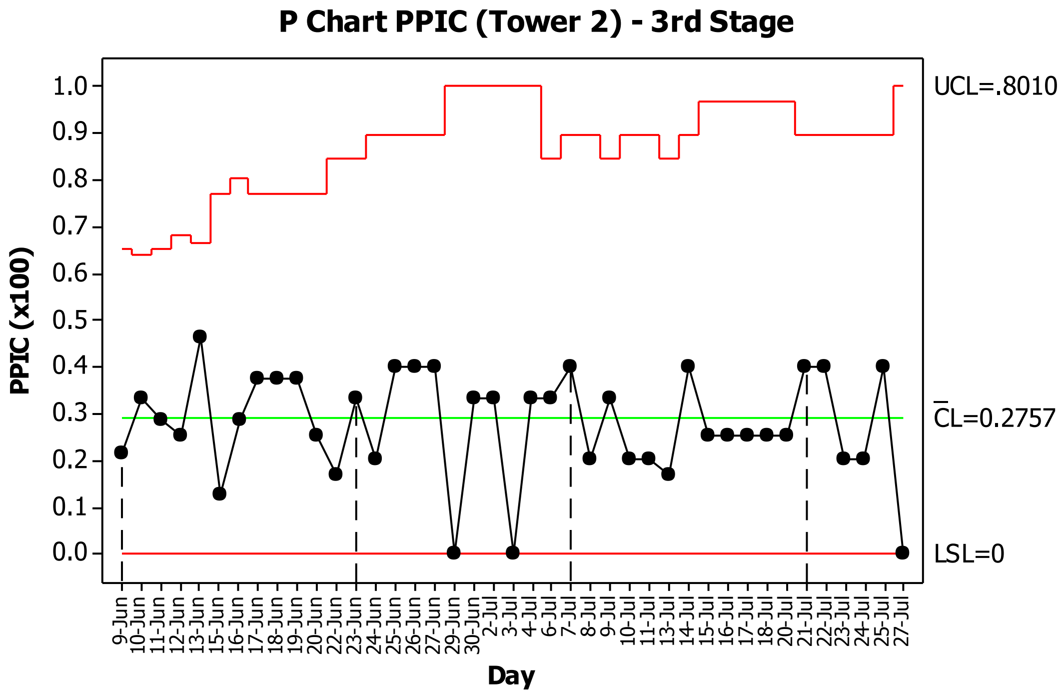


Figure 5.26 P-Chart PPIC (Tower 2) – 3rd Stage

Overall Flow Analysis

From Figures 5.25 and 5.26 it is appreciated the low variability achieved during the Third Stage. In fact, Tower 1 had a difference of 30% between its highest and its lowest PPIC values (40% - 10%). And in Tower 2 this difference was of 46.15% achieved in three days and for the first time the PPIC value of 0%. These values during the Second Stage were of 44.23% for Tower 1, while Tower 2 registered a variability of 48.26%. Therefore, it can be observed that improvements achieved during the Second Stage were successfully maintained and improved further during the Third Stage.

Test Analysis

In the Third Stage, no signals for any test were manifested. This is attributed to the absence of important variability in the workflow derived from the continuously achieved reliability in productions plans after the application of the improved PPP. Therefore, no sudden variations in the workflow related to either good or bad performances were manifested.

General Variations Analysis

In Figures 5.21 and 5.22, an important improvement of rolled PPC can be appreciated in Week 14. By analyzing the PPIC performances during that Week, it is observed that in Tower 1 the lowest PPIC values were achieved in three days over the whole Third Stage period. By detecting the most important frequency reductions of Reasons-NC between Week 13 and Week 14, this improvement could be attributed to reduction of Reasons-NC (2), (4) and (11). Similarly in Tower 2 case, the PPIC value of 0% was registered in Week 14 in two days, and could be attributed to a reduction of Reasons-NC (2), (4) and (10). In order to know whether these improvements were related to the application of the improved PPP, the analysis in the next section was made.

5.3.1.5 Analysis on Production Plans Performance for verifying maintained improvements effects of improved PPP

The discussions in the previous sections demonstrate that improvements achieved during the Second Stage were maintained and improved during the Third Stage. In this section, it was explored in what extent the production plans generated from the improved PPP contributed to such improvements. Such analysis was made by comparing the highest frequency reductions of Reasons-NC with the constraints eliminated in the 'General Coordination Meetings' of the improved PPP. Therefore, if a positive relation existed, the improvements generated by the reduction of frequencies of Reasons-NC can be attributed to the improved PPP. For the purpose of this analysis two tables were generated. Table 5.10 was generated to show the main frequency increments/decrements of Reasons-NC registered between the periods under analysis including Week11-Week12, Week13-Week14, and Week15-Week16. Table 5.11 was also generated to show the constraints detected and eliminated in the Lookahead process during the 'General Coordination Meetings' of the improved PPP and the relation of these constraints with Reasons-NC.

Table 5.10 Frequency increments/decrements of Reasons-NC (Third Stage)

Reasons-NC ID		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Tower 1														
Frequency	Week 9 – Week 10	2	13	9	6	0	0	4	9	0	20	4	0	0
	Week 11 – Week 12	2	5	6	1	0	3	4	7	0	8	1	0	0
Difference		0	**8**	3	**5**	0	3	0	2	0	**12**	3	0	0
Increment (↑) Decrement (↓)		=	↓	↓	↓	=	↑	=	↓	=	↓	↓	=	=
Frequency	Week 11 – Week 12	2	5	6	1	0	3	4	7	0	8	1	0	0
	Week 13 – Week 14	1	4	3	4	0	0	5	2	0	3	4	0	0
Difference		1	1	**3**	3	0	**3**	1	**5**	0	**5**	3	0	0
Increment (↑) Decrement (↓)		↓	↓	↓	↑	=	↓	↑	↓	=	↓	↑	=	=
Frequency	Week 13 – Week 14	1	4	3	4	0	0	5	2	0	3	4	0	0
	Week 15 – Week 16	2	2	2	5	0	0	3	1	0	2	4	0	0
Difference		1	**2**	1	1	0	0	**2**	1	0	1	0	0	0
Increment (↑) Decrement (↓)		↑	↓	↓	↑	=	=	↓	↓	=	↓	=	=	=
Tower 2														
Frequency	Week 9 – Week 10	1	9	8	6	0	0	4	4	0	22	4	0	0
	Week 11 – Week 12	2	5	6	1	0	3	4	7	0	8	1	0	0
Difference		1	**4**	2	**5**	0	3	0	3	0	**14**	3	0	0
Increment (↑) Decrement (↓)		↑	↓	↓	↓	=	↑	=	↑	=	↓	↓	=	=
Frequency	Week 11 – Week 12	2	5	6	1	0	3	4	7	0	8	1	0	0
	Week 13 – Week 14	0	3	2	2	0	0	4	0	0	3	0	0	0
Difference		2	2	**4**	1	0	3	0	**7**	0	**5**	1	0	0
Increment (↑) Decrement (↓)		↓	↓	↓	↑	=	↓	=	↓	=	↓	↓	=	=
Frequency	Week 13 – Week 14	0	3	2	2	0	0	4	0	0	3	0	0	0
	Week 15 – Week 16	0	2	2	5	0	0	2	0	0	2	2	0	0
Difference		0	**1**	0	3	0	0	**2**	0	0	**1**	2	0	0
Increment (↑) Decrement (↓)		=	↓	=	↑	=	=	↓	=	=	↓	↑	=	=

Table 5.11 Constraints eliminated in Third Stage

Screening constraint	Change Order/Priority	Design	Materials	Labor	Equipment	Prerequisite work	Submittals	Transportation	Space
Reason-NC relation	(8)	(6) (7)	(1)(2)	(3)	(3) (5)	(10)	(9)	(1) (3) (11)	(4) (11)
First Meeting (9-Jun)									
Tower 1	9	0	9	4	1	15	0	4	5
Tower 2	4	0	8	8	0	10	0	4	5
Total	13	0	17	12	1	25	0	8	10
Second Meeting (23-Jun)									
Tower 1	6	2	6	3	0	8	0	0	0
Tower 2	6	3	5	2	1	9	0	2	1
Total	12	5	11	5	1	17	0	2	1
Third Meeting (7-Jul)									
Tower 1	3	2	4	1	2	7	0	1	1
Tower 2	3	2	5	2	1	3	0	0	0
Total	6	4	9	3	3	10	0	1	1

Production plan for Week11-Week12 analysis

The first analysis of the Third Stage corresponds to a comparison between the periods Week9-Week10 and Week11-Week12. These periods are selected for analyzing the relation between frequency reductions of Reasons-NC and constraints eliminated in the first 'General Coordination Meeting' of the Third Stage period. This meeting was held on 9-June and generated the production plan for the period Week11-Week12. Table 5.12 presents the Reasons-NC with the highest frequency decrements between Week9-Week10 and Week11-Week12 periods. The data in the table also presents the most constraints eliminated for Week11-Week12 period.

Table 5.12 Comparative information for Week11-Week12 production plan analysis

Tower 1			
Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(10)	12	(10)	15
(2)	8	(2)	9
(4)	5	(8)	9
		(4)	5

Tower 2			
Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(10)	14	(10)	10
(4)	5	(2)	8
(2)	4	(3)	8
		(4)	5

It is noticed from the information above that Reasons-NC (10), (2) and (4) represented the reasons with the highest decrements in frequency between these two periods in both Towers. Moreover, Reasons-NC related to most constraints eliminated in the 'General Coordination Meeting' of 9-June are the same to those Reasons-NC with the highest frequency decrements. Therefore, it can be concluded that the effects of applying the improved PPP generated such improvement.

Moreover, from Table 5.10 it was appreciated that some Reasons-NC instead of presenting decrement in their frequency during the Third Stage had frequency increments such as Reasons-NC (6) and (8). In particular Reason-NC (6) related to 'Changes/redoing work due to design errors' increased in frequency for the inability to detect clashes in the design as constraints in activities. It was also appreciated that as the project advanced in time other Reasons-NC became more dominant, such as Reasons-NC (2) and (4) which are related to 'waiting for materials from supplier' and 'lack of access' respectively. However, constraints detected and eliminated related to this two Reasons-NC (i.e. 'Materials' and 'Space') also increased during Week11-Week12 period, suggesting the effectiveness of the improved PPP in detecting other emerging types of constraints.

Production plan for Week13-Week14 analysis

By implementing improved PPP, production plan for Week13-Week14 period was generated on 23-Jun. For the performance analysis of this plan, a comparison between the periods Week11-Week12 and Week13-Week14 was needed. Table 5.13 presents the Reasons-NC with the highest frequency decrements between Week11-Week12 and Week13-Week14 periods. The data in the table also presents the most constraints eliminated for Week13-Week14 period.

Table 5.13 Comparative information for Week13-Week14 production plan analysis

Tower 1

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(10)	5	(10)	8
(8)	5	(8)	6
(6)	3	(1), (2)	6
(3)	3		

Tower 2

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(8)	7	(10)	9
(10)	5	(1),(2)	5
(3)	4	(8)	6

From the information presented above it is appreciated that constraints related to Reasons-NC (10) and (8) were mostly detected and eliminated from the period Week11-Week12 to Week13-Week14. The elimination of these constraints also provoked the highest reductions in frequency of Reasons-NC. Therefore, this improvement evidences the effects of applying the improved PPP. Reason-NC (6) related to 'Changes and rework due to design errors' also accounted as one of the reasons with high frequency decrement during this period and it can be attributed to 5 constraints eliminated under the screening constraint category 'Design', as seen in Table 5.11. On the other hand, Reasons-NC (4) and (11) with the highest frequency increments between these periods suggest that there are constraints to the concerned activities which were not able to be detected and eliminated in the improved PPP, and these constraints were related to 'lack of access' and 'overcrowded working areas'

Production plan for Week15-Week16 analysis

A further comparison between the periods Week13-Week14 and Week15-Week16 was carried out to analyze the performance of the period from Week 15 to Week 16. Table 5.14 presents the Reasons-NC with the highest frequency decrements between Week13-Week14 and Week15-Week16 periods. The data in the table also presents the most constraints eliminated for Week15-Week16 period.

Table 5.14 Comparative information for Week15-Week16 production plan analysis

Tower 1

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(7)	2	(10)	7
(2)	2	(1), (2)	4
		(8)	3
		(6)	2

Tower 2

Highest frequency decrements		Most Constraints eliminated	
Reason-NC ID	Decrement	Reason-NC ID relation	Eliminated
(7)	2	(1),(2)	9
(10)	1	(10)	5
(2)	1	(8)	6
		(6)	2

From the information presented above, it is observed that decrements in frequency of Reasons-NC were scarce between the two periods. Tower 1 presented only 4 decrements, 2 for Reason-NC (7) and the other 2 for Reason-NC (2). Tower 2 was also in the same condition with only 4 decrements in Reason-NC. This is attributed to the fact that every time the antecedent periods from which comparisons are made were experiencing very similar performances and obtaining almost the same amount of Reasons-NC. In other words, the improvements from the application of the improved PPP were maintained but every time with smaller margins of improvement. However, constraints detection and elimination continued with higher effectiveness, suggesting that root causes of Reasons-NC still existed, which continued creating constraints to activities. Nevertheless, the improved PPP could effectively reduce the effects of these root causes in the production process by helping to detect and eliminate them.

Chapter 6

‘G activities’ and ‘O activities’ – A comparative analysis

CHAPTER 6: ‘G ACTIVITIES’ AND ‘O ACTIVITIES’ – A COMPARATIVE ANALYSIS

6.1 Introduction

In Chapter 5, improvements in the efficiency and effectiveness of the PPP from applying PLAN-SB for delivering more reliable production plans has been verified by means of measurable improvement metrics such as the PPC, rolled PPC and Sigma Level. Concise analyses were also made for identifying the specific sources of such improvements by using different tools like Pareto Charts and P-Charts. However, it is also important to know in what extent PLAN-SB has improved the PPP for enabling sustainability goals to be achieved efficiently and effectively. Chapter 6 presents the examination on the significance of using PLAN-SB by studying Project SB-T2. For conducting the analysis, the activities in Project SB-T2 are grouped into two categories: ‘G activities’ and ‘O activities’. ‘G activities’ are defined in this study as those activities with direct relation to sustainable deliverables, which as a whole define the sustainability performance of a building. And ‘O activities’ are defined as those with no direct relation to sustainable deliverables. Individual and comparative analyses were performed to the two different groups of activities for exploring in what extent PLAN-SB has influenced their production performances, reliability and decrements of reasons for non-completion (Reasons-NC). The same measurable improvement metrics and tools used in Chapter 5 are employed for the analysis in this Chapter, including, PPC, rolled PPC, Sigma Level, Pareto Charts and P-Charts.

6.2 Classification of activities

Activities from which production performance data and Reasons-NC frequencies were collected in Project SB-T2 during the implementation of PLAN-SB were classified into the two different groups of activities (i.e. 'G activities' and 'O activities'). Three professionals were responsible for the classification, including 'The Architect', "The Environmental Engineer" and 'The HK-BEAM Assessor'. 'The Architect' from the architectural firm responsible for designing Project SB-T2 played a main role in the design of environmental friendly features of the project in line with the specifications of the sustainable building assessment and certification system adopted (i.e. 'HK-BEAM 4/04 for New Buildings'). 'The Environmental Engineer' from the environmental firm providing consultancy to the Client and Contractor 'X' played a main role in the definition of construction processes, equipment and materials selection for meeting the specifications of 'HK-BEAM 4/04 for New Buildings'. And, "The HK-BEAM Assessor" from the Business Environment Council (BEC) of Hong Kong, responsible for assessing Project SB-T2 based on the 'HK-BEAM 4/04 for New Buildings'.

The three professionals were provided with a list of activities from Project SB-T2 in which they ticked each activity as 'O activity' or 'G activity' based on their best knowledge of 'HK-BEAM 4/04 for New Buildings' and Project SB-T2. When an activity was ticked as 'G activity' they were asked to give a description of the relation between the activity and a sustainable deliverable by making specific reference to the assessment aspects contained in the 'HK-BEAM 4/04 for New Buildings' assessment framework. A final list of 'O activity' and 'G activity' was prepared by comparing the classifications given by the three experts. The final classification was made when 2 out of 3 or the 3 professionals agreed to classify an activity either as ‘G activity’ or ‘O activity’. When an activity was classified as ‘G activity’ the description of the relation between the activity and a sustainable deliverable was verified by means of the ‘HK-BEAM 4/04 for New Buildings’. The final classification list of activities is included in Appendix D. Based on the final classification list, the ‘G activities’ and ‘O activities’ during the implementation period of PLAN-SB were identified. The total number of ‘G activities’ and ‘O activities’ identified for each Tower and for each implementation Stage are presented in Table 6.1.

Table 6.1 Distribution between ‘G activities’ and ‘O activities’

	First Stage		Second Stage		Third Stage	
Tower 1						
Total activities	457	Proportion	369	Proportion	337	Proportion
O activities	269	58.86%	181	49.05%	151	44.81%
G activities	188	41.14%	188	50.95%	186	55.19%
Tower 2						
Total activities	451	Proportion	366	Proportion	253	Proportion
O activities	266	58.98%	174	47.54%	106	41.90%
G activities	185	41.02%	192	52.46%	147	58.10%

From Table 6.1 it is observed that ‘O activities’ represent the majority during the First Stage, however quantities changed in the following two stages. In the Second Stage, the difference between the two groups of activities was of 1.90% and 4.92% in Tower 1 and Tower 2 respectively, giving the majority to ‘G activities’. And, in the Third Stage this difference augmented reaching 10.81% and 16.20% in Tower 1 and Tower 2 respectively.

It needs to be acknowledged that when the production performance data was collected the project was experiencing a transition from activities mainly related to the superstructure of the towers to more varied activities related to the building façade, architectural finishing and services installations. Thus, the increasing majority of ‘G activities’ could be explained as the results of a higher relation between ‘G activities’ and these varied activities such as façade, architectural finishing and services installations. From Table 6.1, it is also observed that the total number of activities was decreasing from stage to stage, as they were getting closer to the end of the project. Tower 1 always accounted more activities than Tower 2, and this is because Tower 1 contained extra facilities to be built such as the basement car park and the club house.

6.3 PPC vs. rolled PPC Analysis

This section will present a comparative analysis between ‘O activities’ and ‘G activities’ based on PPC and rolled PPC values. The differences of production performances and improvements after PLAN-SB implementation between the two groups of activities will be given. Based on the production performance data collected during the three stages of PLAN-SB implementation, the metrics were calculated for each group of activities, including daily PPC values, Average Weekly PPC values and rolled PPC values. The calculation results were then used to plot graphs of Weekly PPC values vs. rolled PPC values for further analysis. Graphs were prepared for each group of activities, for both Towers, and for each of the three stages.

6.3.1 First Stage Analysis

The First Stage of PLAN-SB implementation was characterized, as defined in Chapter 5, for obtaining the data about production performances and reasons for non-completion (Reasons-NC) of activities before any attempt of improvement in the PPP was made. Therefore, the analysis pursued in this section aims to compare production performances between 'G activities' and 'O activities' by using the PPC and rolled PPP values under the traditional PPP. For graphically introducing the comparison of PPC and rolled PPC for each group of activities and for each tower, Figures 6.1, 6.2, 6.2 and 6.4 were plotted. Table 6.2 was also prepared for highlighting the average PPC and rolled PPC values and the general variability registered in each group of activities.

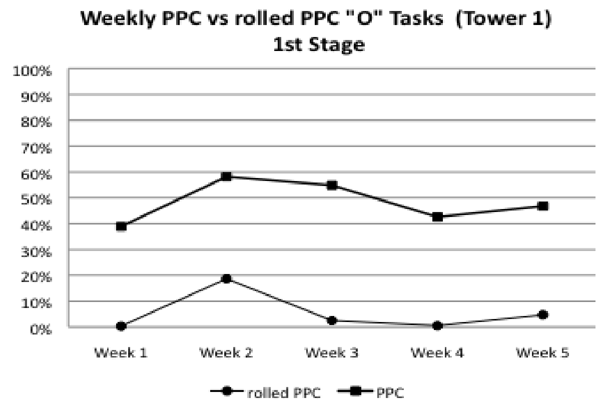


Figure 6.1 Weekly PPC vs. rolled PPC 'O activities' (Tower 1) – 1st Stage

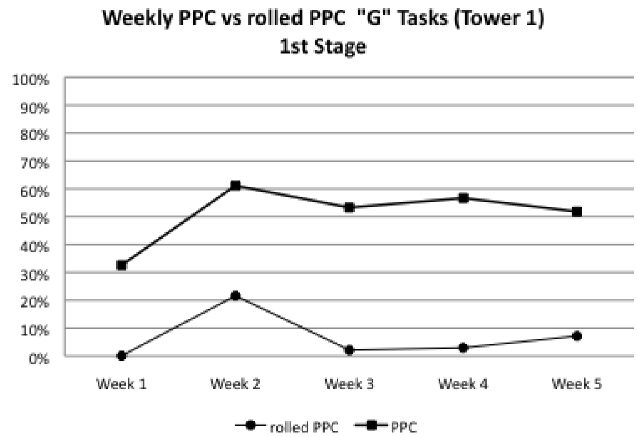


Figure 6.2 Weekly PPC vs. rolled PPC 'G activities' (Tower 1) – 1st Stage

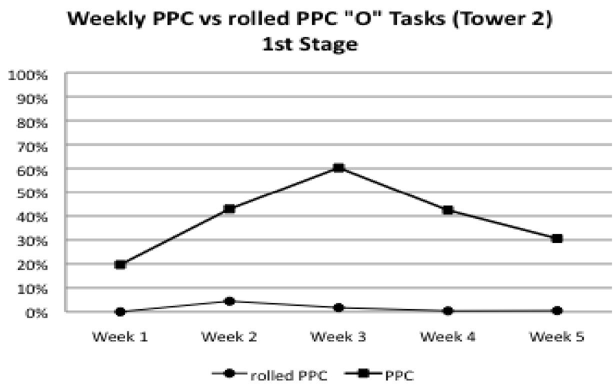


Figure 6.3 Weekly PPC vs. rolled PPC 'O activities' (Tower 2) – 1st Stage

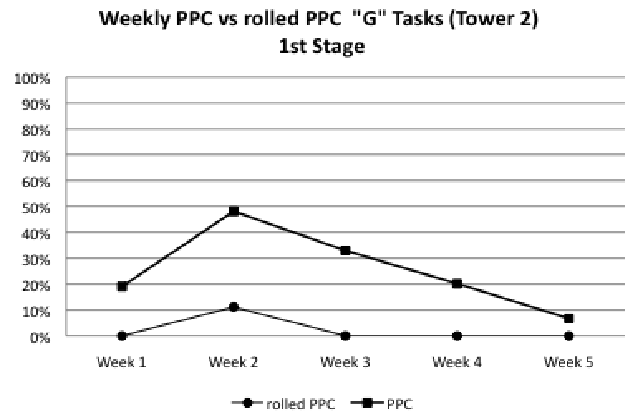


Figure 6.4 Weekly PPC vs. rolled PPC 'G activities' (Tower 2) – 1st Stage

Table 6.2 Weekly PPC and rolled PPC compilation (1st Stage)

	Average PPC	Max Weekly PPC	Min Weekly PPC	Variability	Average rolled PPC	Max rolled PPC	Min rolled PPC	Variability
Tower 1								
O activities	48.24%	58.15%	38.87%	19.28%	5.33%	18.67%	0.30%	18.37%
G activities	51.07%	66.11%	32.59%	33.52%	6.77%	21.60%	0.07%	21.53%
Tower 2								
O activities	39.18%	60.27%	19.68%	40.59%	1.41%	4.44%	0.02%	4.42%
G activities	25.40%	48.15%	6.70%	41.45%	2.23%	11.11%	0.00%	11.11%

From the above information, it is appreciated that 'G activities' had a better PPC performance in Tower 1 with the average PPC of 51.07%. However, in Tower 2 'O activities' presented higher average PPC value of 39.18% than that for 'G activities' giving the average PPC of 25.40%. In fact, it is observed that when a higher average PPC was achieved in both types of activities a lower variability was recorded. For instance in Tower 1, 'G activities' with higher average PPC value of 51.07% was related to a variability range of 33.52%, whilst in Tower 2, 'G activities' with lower average PPC value of 25.40% was related to a variability range of 41.45%. For 'O activities', in Tower 1, higher average PPC value of 48.24% was related to a variability range of 19.28%, whilst in Tower 2, 'O activities' with lower average PPC value of 39.18% was related to a variability range of 40.59%. This is in line with the stated by Thomas et al., (2002) and Gonzalez et al., (2008) who argued that workflow variability appears to be a good indicator of good or poor performance in construction projects.

Moreover, from the Figures 6.1, 6.2 and 6.4 it is appreciated that the highest average PPC and rolled PPC were achieved on Week 2. But in Figure 6.4 it is also observed an important negative tendency registered by 'G activities' from Week 2 until reaching its lowest weekly PPC value in Week 5. The implications of this data will be addressed when analysis is given to reasons for non-completion of activities (Reasons-NC) by using the Pareto Chart tool and the daily PPC values by using the P-Chart tool in later sections.

6.3.2 Second Stage - Analysis

Second Stage of PLAN-SB implementation was the stage in which actions were taken for the improvement of the PPP. Therefore, the analysis pursued in this section aims to compare the improvements achieved between ‘O activities’ and ‘G activities’. Figures 6.5, 6.6, 6.7, and 6.8 were plotted for graphically introducing the comparison of PPC and rolled PPC for each group of activities and for each tower. Table 6.3 was also prepared for highlighting the average PPC and rolled PPC and the general variability registered in each group of activities.

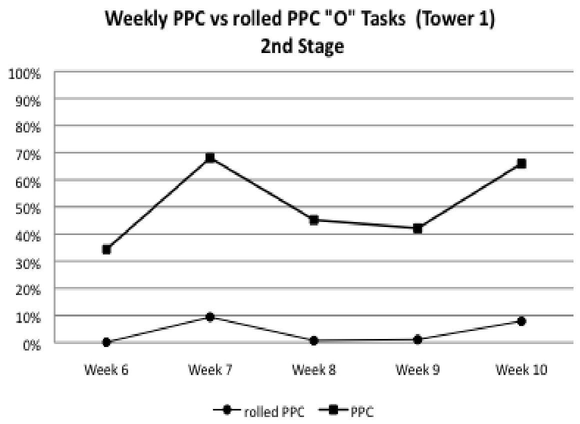


Figure 6.5 Weekly PPC vs. rolled PPC ‘O activities’ (Tower 1) – 2nd Stage

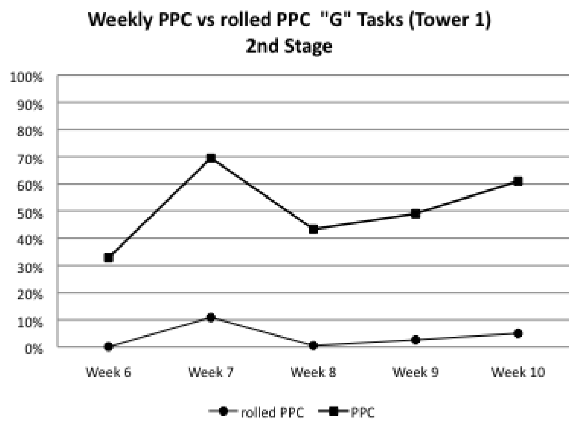


Figure 6.6 Weekly PPC vs. rolled PPC ‘G activities’ (Tower 1) – 2nd Stage

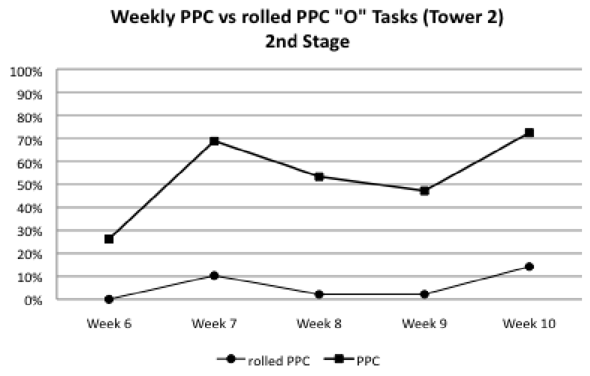


Figure 6.7 Weekly PPC vs. rolled PPC ‘O activities’ (Tower 2) – 2nd Stage

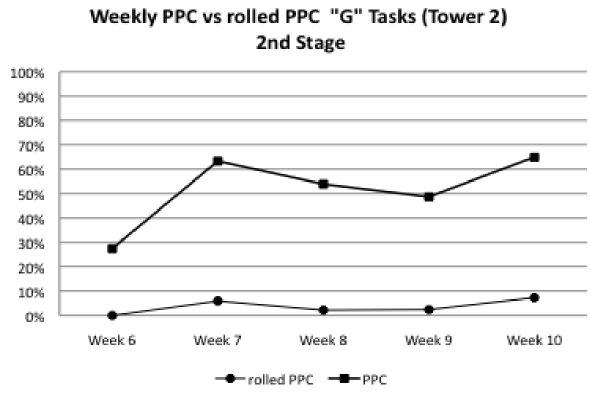


Figure 6.8 Weekly PPC vs. rolled PPC ‘G activities’ (Tower 2) – 2nd Stage

Table 6.3 Weekly PPC and rolled PPC compilation (2nd Stage)

	Average PPC	Max Weekly PPC	Min Weekly PPC	Variability	Average rolled PPC	Max rolled PPC	Min rolled PPC	Variability
Tower 1								
O activities	55.34%	68.06%	42.14%	25.92%	4.77%	9.38%	0.73%	8.65%
G activities	55.73%	69.52%	43.33%	26.19%	4.74%	10.85%	0.49%	10.36%
Tower 2								
O activities	60.44%	72.42%	47.14%	25.28%	7.21%	14.17%	2.16%	12.01%
G activities	57.72%	64.98%	48.67%	16.31%	4.47%	7.29%	2.22%	5.07%

From Table 6.3 it is appreciated that the most important improvements were achieved in Tower 2 in both groups of activities. ‘G activities’ going from and average PPC of 25.40% in the First Stage to 57.72% in the Second Stage, reaching an improvement rate of 127.24%. And, ‘O activities’ from 30.18% to 60.44% average PPC, obtaining an improvement rate of 54.26%. Coupled to the important improvement of ‘G activities’ in Tower 2, a great decrement of variability was recorded between the two Stages, going from 41.45% to 16.31%. In fact, decrements in variability were observed in all groups of activities and in both Towers except for ‘O activities’ in Tower 1. In addition, it is also observed that rolled PPC values continued low during the Second Stage, however the good improvements occurred in Tower 2.

From Figures 6.5, 6.6, 6.7 and 6.8, it is observed an important increment of average PPC and rolled PPC in Week 7. This Week corresponds to the first ‘General Coordination Meeting’ in which the first production plans were obtained from the improved PPP. Therefore, it is considered that the increased reliability of the improved production plan adopted in Week 7, as it was verified in Chapter 5, provoked a general improvement in both groups of activities and in both Towers.

6.3.3 Third Stage - Analysis

Third Stage of PLAN-SB implementation was the stage in which the PPP was monitored for determining in what extent the improvements achieved in the Second Stage were maintained and/or continuously improved. Therefore, the analysis pursued in this section aimed to compare the improvements achieved between Second Stage and Third Stage. Similarly as in the previous two stages analyses, Figures 6.9, 6.10, 6.11 and 6.12 were prepared for illustrating the comparison between PPC and rolled PPC for each group of activities and for each tower. The average PPC and rolled PPC values achieved during the Third Stage and the general variability registered in each group of activities were calculated and are contained in Table 6.4.

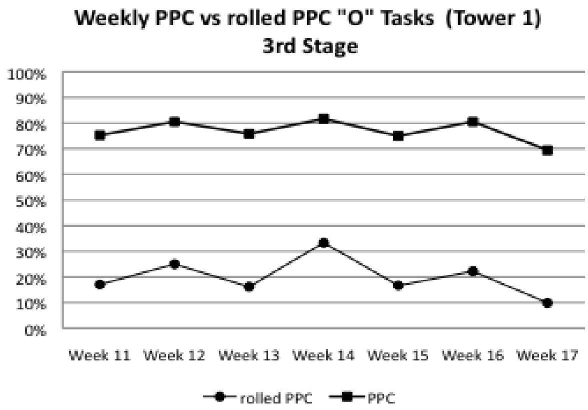


Figure 6.9 Weekly PPC vs. rolled PPC ‘O activities’ (Tower 1) – 3rd Stage

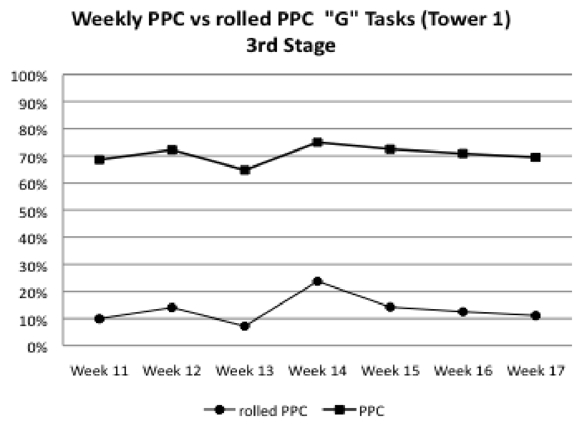


Figure 6.10 Weekly PPC vs. rolled PPC ‘G activities’ (Tower 1) – 3rd Stage

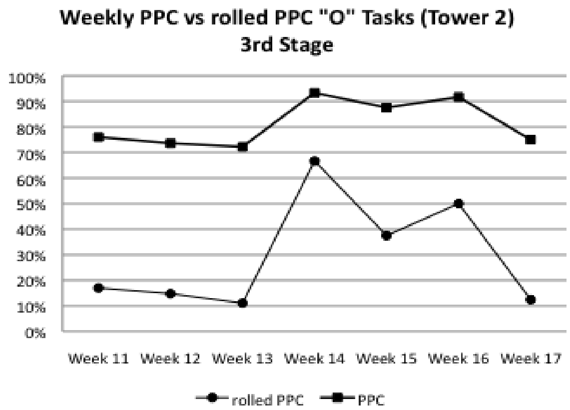


Figure 6.11 Weekly PPC vs. rolled PPC ‘O activities’ (Tower 2) – 3rd Stage

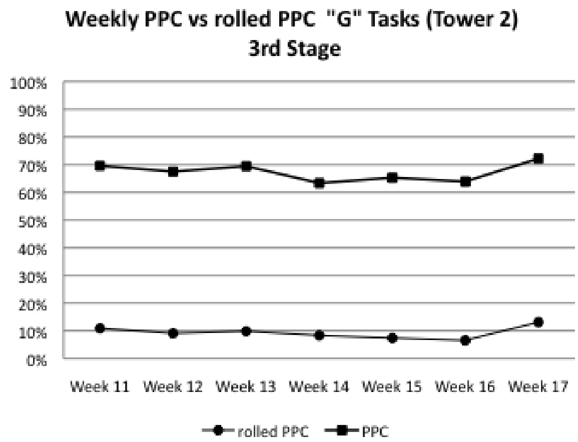


Figure 6.12 Weekly PPC vs. rolled PPC ‘G activities’ (Tower 2) – 3rd Stage

Table 6.4 Weekly PPC and rolled PPC compilation (3rd Stage)

	Average PPC	Max Weekly PPC	Min Weekly PPC	Variability	Average rolled PPC	Max rolled PPC	Min rolled PPC	Variability
Tower 1								
O activities	76.91%	81.67%	69.44%	12.23%	20.05%	33.33%	9.88%	23.45%
G activities	70.47%	75.00%	64.72%	10.28%	13.25%	23.73%	7.20%	16.53%
Tower 2								
O activities	81.34%	93.33%	72.22%	21.11%	24.94%	66.67%	11.11%	55.56%
G activities	67.32%	72.22%	63.33%	8.89%	9.35%	13.17%	6.58%	6.59%

The information presented above shows that average PPC values were higher and variability values were lower during the Third Stage when compared with the previous two Stages. In fact, the highest weekly PPC value achieved during the implementation of PLAN-SB was achieved during this Stage in Tower 2, with the value of 93.33%. Rolled PPC also reached its highest value in the Third Stage in Tower 2 with the value of 66.67%. These best performance values were registered in ‘O activities’ performances.

In general, over the three stages it is observed an increment of average PPC values and decrements in variability in both groups of activities. However, it is only during the Third Stage that ‘O activities’ have shown predominately higher PPC performances than ‘G activities’. While it could be argued that PLAN-SB have shown better results in ‘O activities’, it should also be noticed that ‘O activities’ were higher in number in the First Stage but ‘G activities’ were gradually overtaken that majority as it is seen in Table 6.1. Therefore, the higher the number of ‘G activities’, the higher the probability of having non-completed as scheduled.

By comparing the improvements of average PPC achieved in ‘O activities’ and ‘G activities’ from First Stage to Second Stage, and from Second Stage to Third

Stage, it is appreciated that increments in these values from First Stage to Second Stage were quite different from that achieved from Second Stage to Third Stage are similar. In fact, from Second Stage to Third Stage the highest improvement in average PPC achieved was of 21.57% by 'O activities' in Tower 1 (from 55.34% to 76.91%) and the lowest was of 9.6% by 'G activities' (from 57.72% to 67.32%) giving a range of 11.97% (21.57% – 9.6%). While this range between the First Stage and the Second Stage was of 27.66%. In other words, production plans prepared during the Second Stage helped to equilibrate the PPC performances of both groups of activities in both Towers, and in the Third Stage improvements were more moderated but also more equilibrated among them.

6.4 Analysis of reasons behind 'G activities' and 'O activities' incomplete

In the previous section, the improvements of 'G activities' and 'O activities' over the three Stages of implementation of PLAN-SB were analyzed based on their corresponding PPC and rolled PPC values. Such analyses provided support to verify that improvement was achieved after implementation and that it could be maintained over time. The discussion in Chapter 5 suggests that the improvement of PPC values was related with the reduction of frequency of reasons for non-completion (Reasons-NC) of activities. Therefore, it is the purpose of this section to examine what Reasons-NC were dominants in 'O activities' and 'G activities' and how these were reducing their frequency over the three Stages. In addition, a comparative analysis was made between the Reasons-NC related to each group of activities and which reduced their frequency in a higher extent with the Reasons-NC related to the higher number of constraints eliminated in the PPP. This comparative analysis had the purpose to examine in what extent and how different PLAN-SB influenced the reduction of frequency of Reasons-NC related to each group of activities.

For the purpose of the analysis of Reasons-NC, 12 Pareto Charts were prepared: covering the two groups of activities for the two towers and for each of the three stages, namely, 2*2*3=12. These 12 charts were used for visually exposing the Reasons-NC that gave 80% accumulated frequencies from the total frequencies in the individual charts. The 12 Pareto Charts are presented from Figure 6.13 to Figure 6.24 in Appendix E. By using the 12 Pareto Charts, Table 6.5 was generated in order to present the Reasons-NC that were in the accumulated of 80% of all frequencies in each group of activities, in each tower and for each Stage. Thus, Table 6.5 helps to highlight the Reasons-NC that caused most of the uncompleted activities. The Reasons-NC in Table 6.5 were replaced with their corresponding ID numbers as assigned in Table 4.2 for facilitating the analysis.

Table 6.5 Comparative of Reasons-NC with higher frequency

		'O activities'	'G activities'
First Stage			
Reason-NC ID	T1	(10) (8) (3)	(10) (3) (8)
	T2	(10) (8) (13) (3)	(10) (8) (3)(2)
Second Stage			
Reason-NC ID	T1	(10) (8) (2) (3)(11)	(10) (8) (3) (2)(7)(1)
	T2	(10) (2) (3) (8)(1)(4)	(10) (3) (2) (8)(7)(11)
Third Stage			
Reason-NC ID	T1	(7) (2) (10) (3)(4)(11)	(10) (2) (3) (7)(8)(11)
	T2	(10) (4) (2) (3)(7)	(10) (4) (7) (2)(3)

From Table 6.5 it is appreciated that in the First Stage 80%-frequency causes for the incompletion of activities for 'O activities' were No. (13), (10), (8) and (3) Reasons-NC for both Tower 1 and 2, and that for 'G activities' were No. (10), (8),

(3) and (2) Reasons-NC for both Tower 1 and 2. According to the rule '80/20' as introduced in Sections 4.5.1 and 5.2.1.1, by concentrating on the reduction of these four Reasons-NC, 80% of the causes for incomplete activities would be eliminated.

In the Second Stage, actions for the improvement of the PPP were taken. As a result, the happening frequencies of the Reasons-NC (10), (3) and (8) were reduced. In order to get 80% accumulated frequencies, more Reasons-NC would be included to share the accumulated 80% value. Thus, from Table 6.5, in the Second Stage 80% of the causes for the incompletion of activities was attributed by five to six Reasons-NC in Tower 1 and 2 for both 'O' and 'G' activities.

Finally, in the Third Stage of the PLAN-SB implementation, it is noted that the number of 80%-frequency Reasons-NC remains to five to six, however they were different ones. For instance, Reasons-NC (8) and (3) were reported less frequent during the Third Stage and were replaced by Reasons-NC (7), (2) and (4) which were reported with a higher occurring frequency. Moreover, it can also be observed that Reason-NC (10) was the most frequent-occurring Reason-NC in all stages for both 'G activities' and 'O activities' except in the third stage for 'O activities'.

Once having identified the Reasons-NC with higher occurring frequency by the type of activity and by Tower, Table 6.6 is generated with the purpose to show which Reasons-NC were recurrently the ones with higher frequency over the three stages in both 'O activities' and 'G activities'. The maximum number of the incidence happened to the Reasons-NC is 12, representing that the concerned cause happened in all 12 possible cases (i.e. in the two groups of activities, in the two towers and in each of the three stages, 2*2*3=12). And the minimum total achievable is 0 representing no incidence in any of the cases.

Table 6.6 Number of incidence happened to the Reasons-NC as highly frequent

Reason-NC ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Incidence in O activities	1	4	6	3	0	0	2	4	0	6	2	0	1
Incidence in G activities	1	5*	6	1	0	0	4*	5*	0	6	2	0	0
Total	2	**9**	**12**	4	0	0	**6**	**9**	0	**12**	2	0	1

Table 6.6 indicates that Reasons-NC (2), (8) and (7) had higher incidence in 'G activities' than that in "O activities'. Only Reasons-NC (4) had higher incidence in 'O activities' than that in 'G activities'. Table 6.6 shows that Reasons-NC (10) and (3) were the most recurrent having highest frequency in all possible cases. These two most frequent reasons were followed by Reasons-NC (2) and (8) with 9 incidence cases, and Reasons-NC (7) in 6 cases.

Having identified the Reasons-NC with highest incidence, the '80/20' rule is applied for selecting the Reasons-NC with higher influence in the Project SB-T2 and explore how these decremented/incremented their frequencies over the three Stages. Thus, 20% of the total 13 Reasons-NC (i.e. 3 Reasons-NC) reporting the highest incidences in all cases as reported in Table 6.6 were selected for the analysis. As (10) and (3) have same frequency, and the same to (8) and (2), the reasons selected are (10 (3) (8) and (2) (7). For the analysis purposes, individual frequencies of these selected reasons were obtained from the compilation of Reasons-NC for 'G and O activities' collected from on-site observations and contained in Appendix B. Having obtained this information, the decrement and increment rates (whatever the case was) were calculated for each Reasons-NC in order to identify the ones that had higher decrement rates after the improvement of the PPP and whether these were related to ‘G activities’ or ‘O activities’. Decrement and increment rates are compiled in Table 6.7

Table 6.7 Decrement/Increment rates of Reasons-NC

		First Stage		Second Stage		Third Stage
Tower 1						
Decrement/Increment rate			54.10% ↓		71.43% ↓	
Frequency of Reason-NC (10)	O	61		28		8
	G	36		18		7
Decrement/Increment rate			41.67% ↓		66.67% ↓	
Decrement/Increment rate			45.45% ↓		41.67% ↓	
Frequency of Reason-NC (3)	O	22		12		7
	G	28		12		5
Decrement/Increment rate			57.14% ↓		58.33% ↓	
Decrement/Increment rate			45.16% ↓		70.59% ↓	
Frequency of Reason-NC (8)	O	31		17		5
	G	14		14		5
Decrement/Increment rate			0.00%		64.29% ↓	
Decrement/Increment rate			300.00% ↑		50.00% ↓	
Frequency of Reason-NC (2)	O	4		16		8
	G	8		11		5
Decrement/Increment rate			37.50% ↑		54.55% ↓	
Decrement/Increment rate			600.00% ↑		28.57% ↑	
Frequency of Reason-NC (7)	O	1		7		9
	G	1		7		5
Decrement/Increment rate			600.00% ↑		28.57% ↓	
Tower 2						
Decrement/Increment rate			50.00% ↓		67.86% ↓	
Frequency of Reason-NC (10)	O	56		28		9
	G	47		24		14
Decrement rate			48.94% ↓		41.67% ↓	
Decrement/Increment rate			25.00% ↓		41.67% ↓	
Frequency of Reason-NC (3)	O	16		12		7
	G	21		11		10
Decrement rate			47.62% ↓		9.09% ↓	
Decrement/Increment rate			65.71% ↓		83.33% ↓	
Frequency of Reason-NC (8)	O	35		12		2
	G	24		8		4
Decrement rate			66.67% ↓		50.00% ↓	
Decrement/Increment rate			77.78% ↑		56.25% ↓	
Frequency of Reason-NC (2)	O	9		16		7
	G	18		9		12
Decrement/Increment rate			50.00% ↓		33.33% ↑	
Decrement/Increment rate			600.00% ↑		0.00%	
Frequency of Reason-NC (7)	O	1		7		7
	G	1		6		13
Decrement/Increment rate			500.00% ↑		116.67% ↑	

Key: Decrement (↓); Increment (↑):

6.4.1 Analysis to the changes from First Stage to Second Stage

It is in Second Stage where the first increments/decrements in the frequencies of Reasons-NC can be observed after the improvement of the PPP. Therefore, the frequencies obtained during the Second Stage are compared with the ones in the First Stage in order to investigate in what extent the frequencies of the Reasons-NC under analysis were influenced.

From Table 6.7 it can be appreciated that in general both 'G activities' and 'O activities' had significant decrement rates of incompletion incidences. Some Reasons-NC such as No. (10) had very high frequency decrements in both 'G activities' and 'O activities'. Nevertheless, not all Reasons-NC had decrements between these two stages. For instance, Reason-NC (2) related to 'waiting for materials from supplier' and (7) relating to 'changes/redoing work due to site errors' had significant increments. This implies that the improved PPP was not able to effectively detect and eliminate constraints from activities related to these two Reasons-NC. The constraints related to these two Reasons-NC have been discussed previously in Chapter 5 as difficult to eliminate. In particular frequency decrements of Reason-NC (2) are related to the elimination of activity constraints which depend on the good communication and coordination with the suppliers and the availability of special materials. This might also be the explanation of why Reason-NC (2) is more frequent in 'G activities' as appreciated in Table 6.6. Reason-NC (7), also more frequent in 'G activities', is related to site errors due to lack of understanding of the design, and the use of wrong materials or construction process, which consequently are more difficult to predict and eliminate as an execution constraint from activities. As these are more uncertain and difficult to control, it is difficult to eliminate. It also appears that more 'G activities' is associated with more Reasons (2) and (7). This relation between the two Reasons-NC (2) and (7) with 'G activities' may suggest that the increment of 'G activities' during the Second Stage may also be an important cause behind the increment of these two Reasons-NC.

6.4.2 Analysis to the changes from Second Stage to Third Stage Analysis

By comparing the frequencies obtained in the Second Stage with the ones in the Third Stage, it is observed that higher decrements rates were obtained. Achievements were also made from increment to decrement tendencies. From Table 6.7 there are two important decrements identified. The first one relates to the Reason-NC (10) for 'O activities' in Tower 1. This reason had a frequency of 61 in the First Stage, then reduced to a frequency of 28 in the Second Stage and finally diminished to a frequency of only 8 in the Third Stage. Another important decrement of frequency relates to Reason-NC (8) for 'O activities' in Tower 2. The frequency of this Reasons-NC reduced from a frequency of 35 in the First Stage to a frequency of 12 in the Second Stage, and finally to a frequency of 2 in the Third Stage.

From Table 6.7 it is also observed that majority of the frequency increments reported during the Second Stage changed to decrements during the Third Stage. Major changes occurred in Reason-NC (7) related to 'G activities' in Tower 1, changed from an increment rate of 600% to a decrement rate of 28.57%. Another major change happened to the Reason-NC (2) related to 'O activities' in Tower 1, changed from an increment rate of 300% to a decrement rate of 50%. These improvements imply that PLAN-SB helped to effectively achieve continuous decrements in Reasons-NC and when increments were experienced, turnovers to decrements were achieved overtime.

6.5 P-Chart Analysis for identifying special causes contributing to variations

In the previous section, Pareto Charts have helped to identify the main Reasons-NC causing activities incomplete and consequently variability in the workflow related to both ‘G activities’ and ‘O activities’. However, as discussed in Chapter 5, variations are inherent in any process and these can be attributed to either common causes or special causes. Special causes are those that create sudden variations in the workflow and generally conduce to critical delays in the process. Therefore, it is very important to find out these special causes to variations, and solutions to mitigate the causes can be taken. It is the purpose of this section to identify the special causes which attribute to variations in the workflow of ‘G activities’ and ‘O activities’ during the three stages, Comparison analysis between these causes and the two types of activities will be given as well.

The discussion in Chapter 5 demonstrates that P-Chart is a popular tool for determining the special causes behind variability in the workflow. And this tool has been adopted effectively in Chapter 5 when identifying special causes related to major variability in the workflow before and after the application of the improved PPP. Therefore, the P-Chart tool is adopted in this section for identifying the special causes related to variations in the workflow of ‘G activities’ and ‘O activities’. As a result, 12 P-Charts were plotted (covering the two groups of activities for the two towers and for each of the three stages, 2*2*3=12). These 12 P-Charts are presented from Figure 6.25 to Figure 6.36 in

Appendix F. The analysis here is focused on those P-Charts which demonstrate special variations.

6.5.1 Identification for special variation causes in First Stage

For the identification of special variation causes in the First Stage, P-Charts were generated by using the PPC values obtained from the production performance of ‘G activities’ and ‘O activities’ during the First Stage. The method of generating these charts is the same as that adopted in Chapter 5 where the P-Charts were produced. During the First Stage, the workflow of ‘G activities’ in Tower 1 was depicted as Figure 6.26 and the workflow of ‘O activities’ in Tower 2 depicted as Figure 6.27, which presented the most important variations.

In Figure 6.26, the maximum variability range of 63.49% was found, which is from a Percent Plan Incomplete (PPIC) of 85.71% recorded on 02-April to a PPIC of 22.22% recorded on 8-April. Similarly, in Figure 6.27, a maximum variability range of 90% was found, from a PPIC of 100% recorded on 02-April to a PPIC of 10% recorded on 16-April.

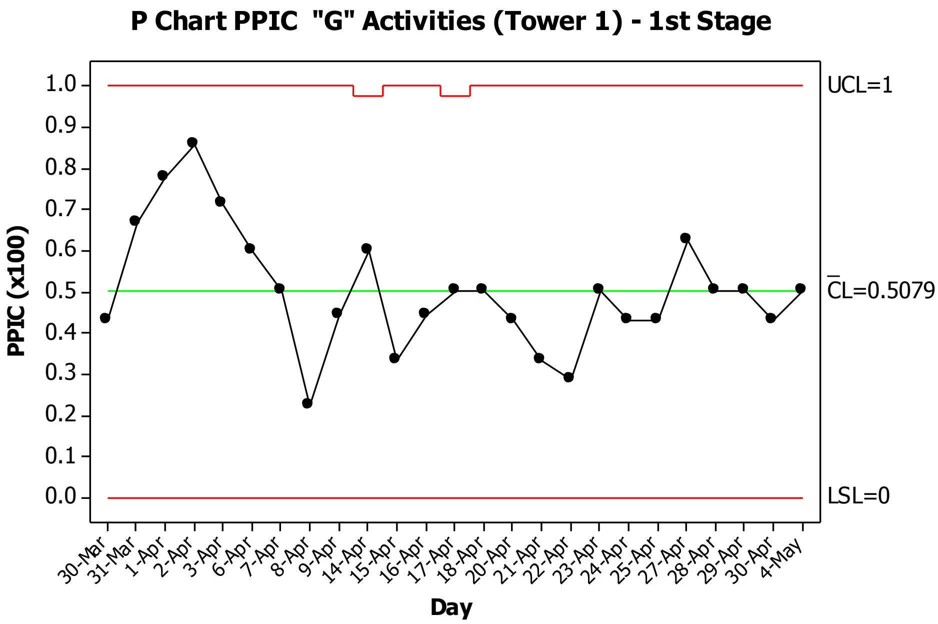


Figure 6.26 P-Chart PPIC 'G activities' (Tower 1) – 1st Stage

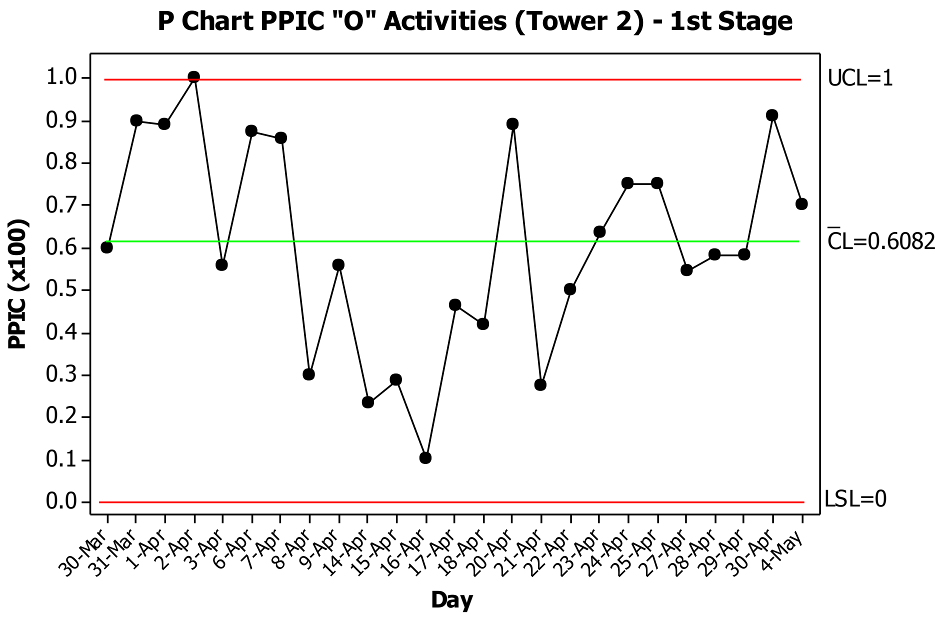


Figure 6.27 P-Chart PPIC 'O activities' (Tower 2) – 1st Stage

In Figure 6.26, it is appreciated that the reduction tendency of PPIC values started in the transition between Week 1 (30-Mar-06Apr) and Week 2 (07-Apr-09Apr). The reduction is significant and it is therefore good opportunity to identify the causes which triggered the improvement, for example, which Reasons-NC decreases between the two weeks. . By examining the compilation of Reasons-NC for ‘G and O activities’ in the First Stage (See Appendix B), it was found that from Week 1 to Week 2 the main frequency reductions were in Reasons-NC (2), (3) and (10).

Similarly, in Figure 6.27 it is observed that the reduction tendency of PPIC values started in the transition between Week 1 (30-Mar-06Apr) and Week 3 (14-Apr-20Apr), and the main frequency reductions of Reasons-NC between these weeks were: (3), (10) and (13)[6].

6.5.2 Identification for special variations causes in Second Stage

During the Second Stage, it is observed that the workflow of ‘G activities’ in Tower 1 depicted in Figure 6.30 and the workflow of ‘O activities’ in Tower 2 depicted in Figure 6.31 presented the most important variations, both cases triggering the signal test #2, which is to test where there is any special causes related to an improvement of PPIC which was maintained for at least 9 consecutive times under CL. In this case, the Test has evidenced one special cause.

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6 Due the unfamiliarity with the ‘Reasons-NC’ given to the foremen for recording the data during the first week, and excessive use of ‘other’ (13) as a reason for non-completion was experienced. Thus, its frequency reduction in the second week is directly related to the better use of the tool but alien to the PPP itself.

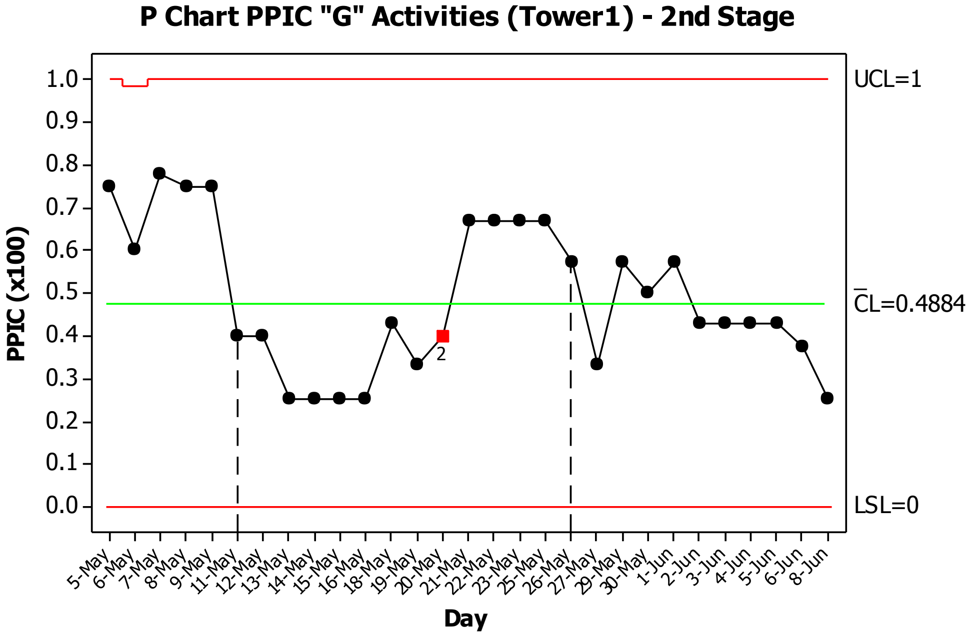


Figure 6.30 P-Chart PPIC 'G activities' (Tower 1) – 2nd Stage

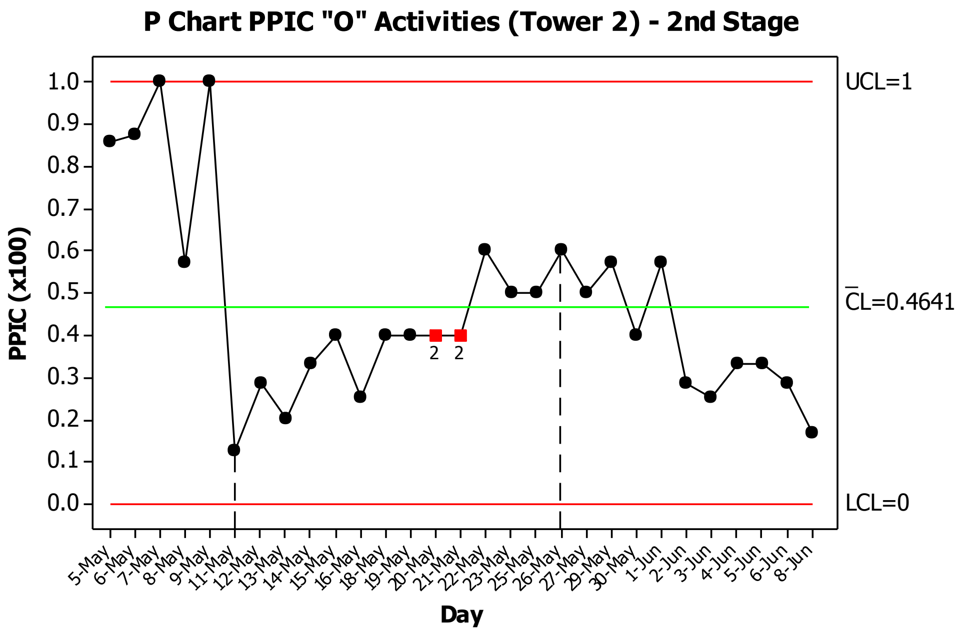


Figure 6.31 P-Chart PPIC 'O activities' (Tower 2) – 2nd Stage

In Figure 6.30, the improvement of PPIC started in the transition between Week 6 (05-May-11May) and Week 7 (12May-18May). Thus, it is significant to identify the main frequency reductions of Reasons-NC between these two weeks for determining what triggered such improvement. By examining the compilation of Reasons-NC for ‘G and O activities’ in the Second Stage (See Appendix B), it was found that from Week 6 to Week 7 the main frequency reductions were in Reasons-NC: (3), (8) and (10).

Similarly, in Figure 6.31, it is observed that the improvement detected by Test #2 started in the transition between Week 6 (05-May-11May) and Week 7 (12May-18May), and the main frequency reductions of Reasons -NC between these two weeks were: (3), (6) (10) and (11).

6.5.3 Identification for special variation causes in Third Stage

Finally, during the Third Stage more reliable workflows are observed in both types of activities and in both towers, evidenced by the fact that no significant variability was found. In these contents, the workflows that have achieved better PPIC values (in this case 0% PPIC values) are selected for analysis in order to identify what were the main Reasons-NC reductions that triggered such achievement. During the Third Stage it is observed that the workflow of ‘O activities’ in Tower 2 depicted in Figure 6.35 and the workflow of ‘G activities’ in Tower 2 depicted in Figure 6.36 presented the higher number of ‘0% PPIC values’ achieved by each type of activities. Therefore, these two figures were used for analysis.

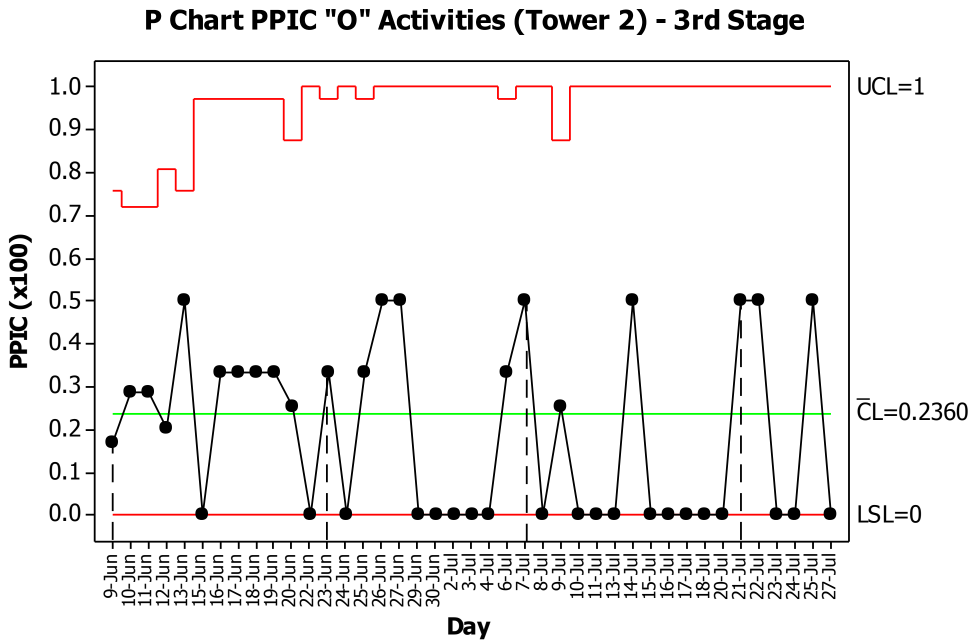


Figure 6.35 P-Chart PPIC 'O activities' (Tower 2) – 3rd Stage

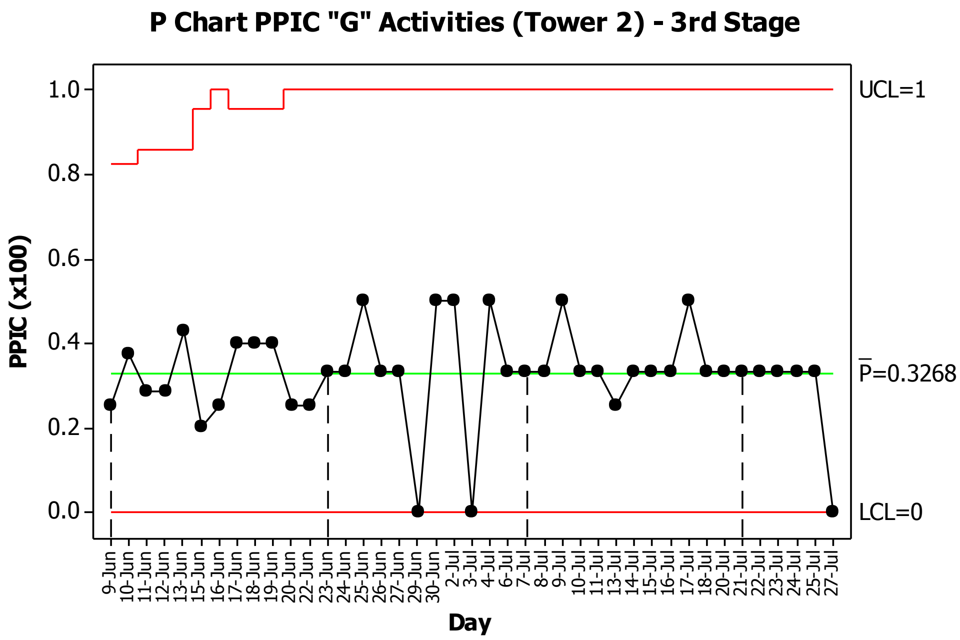


Figure 6.36 P-Chart PPIC 'G activities' (Tower 2) – 3rd Stage

In Figure 6.35, it is appreciated that ‘0% PPIC values’ were achieved five consecutive times in the transition between Week 13 (23June-29June) and Week 14 (30June-06July) and between Week 15 (07July-13July) and Week 16 (14July-20July). Thus, it is significant to identify the main frequency reductions of Reasons-NC between these weeks for determining what triggered such improvement. By examining the compilation of Reasons-NC for ‘G and O activities’ in the Third Stage from Appendix B, it was found that from Week 13 to Week 14 the main frequency reductions were in Reasons-NC: (3), (4), (7), and (10); and from Week 15 to Week 16 the main frequency reductions were in Reasons-NC: (2), (4) and (11).

Similarly in Figure 6.36, it is observed that the achievement of two ‘0% PPIC values’ was in the transition between Week13 and Week 14 and the main frequency reductions of Reasons -NC between these two weeks were: (2), (4) and (10).

6.5.4 Comparison Analysis

It is the purpose of this comparative analysis to find out if the Reasons-NC behind the most important production performance improvements in the workflow (PPIC values reduction tendency) as identified in this section are the same as the ones related with the higher number of activity constraints eliminated in the PPP during Second and Third Stage respectively as identified in Chapter 5. For the purpose of the comparative analysis, Table 6.8 was generated for comparing the Reasons-NC related to the production performance improvements and the Reasons-NC related to constraints eliminated for each Stage.

Table 6.8 Comparative of Reasons-NC related to positive variability and constraints eliminated

	Reasons-NC related to production performance improvements	Reasons-NC related to constraints eliminated
Second Stage		
'G activities'	(3) (8) (10)	(10) (3) (8)
'O activities'	(3) (6) (10) (11)	
Third Stage		
'G activities'	(2) (4) (11)	(10) (2) (8) (3)
'O activities'	(2) (3) (4) (7) (10) (11)	

From Table 6.8 it is observed that Reasons-NC (3), (8) and (10) related to production performance improvements in 'G activities' during the Second Stage are the same as the Reasons-NC related to constraints which have been eliminated as results of using the improved PPP. Reasons-NC (10) and (3) related to production performance improvements in 'O activities' are also the same as those Reasons-NC related to constraints eliminated. In the Third Stage, relations between reductions in frequency of Reasons-NC with constraints eliminated as results of using the improved PPP have also been found in Reasons-NC (10), (2) and (3). It is particularly interesting to note the Reason-NC (2): when there was an increase of constraints eliminated in relation to Reasons-NC (2) in the Third Stage, the reason was also a main cause for production performance improvements for both 'G activities' and 'O activities'.

In general, it is observed a positive relation between constraints eliminated by the improved PPP with the most significant production performance improvements conducing to achieve the lowest PPIC values as encountered in the P-Charts. Thus, it can be concluded that the production performance improvements achieved due to reduction in frequency of Reasons-NC (10), (3), (8) and (2) were mainly caused for the positive effects of the improved PPP.

6.6 Sigma Level Analysis

Through the analysis in this Chapter, the production performance improvements in 'G activities' and 'O activities' and the reduction of variability in their workflows have been demonstrated during the implementation of PLAN-SB. However, improvements have been achieved in both types of activities indistinctively. Therefore, it is the purpose of this section to find out what type of activities beneficiated the most from the implementation of PLAN-SB.

Sigma level, as discussed in Chapter 2, was developed as a universal quality metric that could help to benchmark different products or processes regardless of their complexities and dissimilarities between them. Thus, by using the properties of Sigma Level, the Sigma values obtained from 'G activities' and 'O activities' respectively were benchmarked in order to determine what type of activities obtained better production performance improvements over the three stages of PLAN-SB implementation.

Based on the calculation results for the PPC values for 'G activities' and 'O activities' which have been obtained in Section 6.3, Sigma Levels were calculated (according to the principles introduced in Chapter 4) for each type of activity in both Towers and for each Stage, which has been shown in Table 6.9. In Table 6.9, Sigma Levels were concentrated and the improvement rates were calculated from Stage to Stage for determining which activities had the highest improvements.

Table 6.9 Improvement rates of Sigma Levels

	First Stage		Second Stage		Third Stage
Tower 1					
Sigma Level-O activities	2.52		2.66		3.20
Improvement rate		5.56%		20.30%	
Sigma Level-G activities	2.57		2.67		3.06
Improvement rate		3.89%		14.61%	
Tower 2					
Sigma Level-O activities	2.29		2.68		3.30
Improvement rate		17.03%		23.13%	
Sigma Level-G activities	1.98		2.67		2.99
Improvement rate		34.84%		12.41%	

From Table 6.9 it is observed that both types of activities had a continuous improvement over the three stages. ‘O activities’ predominately achieved higher improvement rates, however the highest improvement rate achieved (34.84%) belonged to ‘G activities’ and was obtained from First Stage to Second Stage in Tower 2. It is also in Tower 2 but from Second Stage to Third Stage that ‘O activities’ achieved its highest improvement rate (23.13%). Thus, it can be implied that ‘O activities’ had a better response to the improvements made to the PPP through the implementation of PLAN-SB, although important improvements have also been achieved by ‘G activities’. However, constraints related to the ‘G activities’ involved more difficulties to detect and eliminate, therefore their improvement rates were not as high as that achieved by ‘O activities’. It should also be noticed that ‘G activities’ gradually became higher in number through the three stages, consequently the possibilities of incomplete activities from ‘G activities’ were also higher.

Finally, it is observed that the highest Sigma Levels achieved were 3.30 and 3.06 from ‘O activities’ and ‘G activities’ respectively. It is considered that significant improvements have been achieved.

Chapter 7

Discussions

CHAPTER 7: DISCUSSIONS

7.1 Introduction

This chapter discusses the findings obtained from the implementation of PLAN-SB in Project SB-T2. As introduced in Chapter 3, the generic principles of the action research method and the DMAIC (Define, Measure, Analysis, Improve and Control) framework from Six Sigma were applied in this research for the implementation of PLAN-SB by means of a case study. The implementation process was divided in three main stages, namely First Stage (including Define and Measure steps), Second Stage (including Analysis and Improve steps), and Third Stage (including Control step). Through these three stages of implementation, there is strong evidence to support the hypothesis of this research that the adoption of a production planning system based on Lean Construction principles and Six Sigma methodology can improve the efficiency and effectiveness in the implementation and delivery of sustainable building projects.

7.2 Discussion on the findings from the First Stage of PLAN-SB implementation

This section discusses the findings from the First Stage of PLAN-SB implementation in Project SB-T2. This stage was divided into two main steps, namely Define and Measure steps with the common purpose of providing with information about the process to be improved (i.e. PPP) and identify potential areas for improvement.

7.2.1 Define step

This section discusses the main findings obtained during the Define Step. The Define step had the main purpose of providing with information which could help to document the Production Planning Process (PPP) in Project SB-T2 for its analysis. In that content, PLAN-SB adopted various tools namely, Organizational Structure Chart, SIPOC Diagram, Flow Diagram and Project Charter. The application of these tools in the implementation has proved to be efficient and effective for documenting the PPP and assisting in the identification of potential areas for improvement. The following are major examples:

From the Organizational Structure Chart, it was possible to identify the main project team members and their different roles with direct participation in the PPP. It was from this diagram that it was also possible to identify the main project team members responsible for generating the preliminary production plans (i.e. Assistant Building Engineer (1) and (2)) and to know that they were supervised by an off-site project team member (i.e. Planning Manager). This information together with the Flow Diagram of the PPP helped to identify the first potential area for improvement (i.e. First revision and approval stage of preliminary production plans) in the PPP as addressed in Section 5.1.1.6.

From the SIPOC Diagram, it was possible to identify the main information (Inputs) necessary for generating the production plans in the original PPP of Project SB-T2 and identification of the project team members that used the production plans (Customers). By identifying who were the ‘Customers’, it was possible to examine in what extent they were satisfied with the quality of the production plans generated by adopting the original PPP. It was found that in general ‘Customers’ did not regard the production plans as bad quality plans, but with important opportunities for improvement. For instance, sub-contractors and foremen considered that production plans poorly considered the actual constraints and objectives of the construction environment while suppliers considered that activities were not executed in due time as specified in the production plans. These disconformities on the quality of production plans suggested the use of a traditional Push Planning System in the original PPP which was later confirmed in the PPP Flow Diagram and defined as potential area for improvement, as seen in Section 5.1.1.6.

From the Flow Diagram of the PPP, it was possible to have a visual representation of the original PPP which helped to define all major steps and the interfaces between various contributors and how the process itself flowed through the organization. By examining the main steps of the PPP it was possible to confirm that the original PPP in Project SB-T2 was based on a traditional Push Planning System. A second potential area for improvement in the original PPP in Project SB-T2 was suggested as the change from a Push Planning System to a Pull Planning System. This was identified based on the opinions obtained from the ‘Customers’ suggesting the opportunity for improvement in the quality of production plans in Section 5.1.1.3, and based on the literature suggesting the better performance of production plans by using a Pull Planning System in Section 2.3.3.Moreover, the Flow Diagram of the PPP also helped to identify a third potential area for improvement in the final revision and approval of production plans, since it was regarded as a weak consensual final decision for making production plans ready for distribution.

From the Implementation Project Charter of PLAN-SB, it was possible to define the terms and resources for enabling and enhancing the possibilities of systematically achieving the steps of PLAN-SB implementation. In this content, the Project Charter effectively functioned as a communication document for facilitating the introduction of PLAN-SB implementation in Project SB-T2 by informing the key issues, including the perceived problems in the original PPP, the improvement goals statements, the scope, the timing and who were in the implementation team. The Project Charter was used in meetings and reports for introducing PLAN-SB implementation project and/or as reference document.

In summary, it was by means of all these tools including Organizational Structure Chart, SIPOC Diagram, Flow Chart and Project Charter that the PPP was documented and by its analysis three potential areas for improvement were identified. In a later stage, the accuracy of the identification of these potential areas was supported by the performance measurement of the PPP evidencing problems in the same areas. These areas were: (1) First revision and approval stage of preliminary production plans, (2) Traditional Push Planning System, and (3) Final revision and approval of production plans.

7.2.2 Measure step

In this section the main findings obtained in the Measure step are discussed. The measure step had two main purposes: (1) to measure the reliability performance of production plans before any attempt of improvement in the PPP was made, and (2) to explore the differences in performances between ‘G activities’ and ‘O activities’. In this content, three metrics with different qualities each one were proposed for measuring the performance of the PPP, these three metrics are Percent Plan Complete (PPC), rolled PPP, and Sigma Level. The principles of these metrics have been presented in Chapter 4.

7.2.2.1 Discussion on the findings from the PPP performance measurement results before improvement actions

From the implementation of PLAN-SB, the application of PPC, rolled PPC and Sigma Level has proved to be an efficient and effective way to accurately communicate the PPP performance and assist in the comparison of 'G activities' and 'O activities' performances. The data about performance of production plans in both towers and for both types of activities obtained during the First Stage of implementation of PLAN-SB are contained in Table 7.1

Table 7.1. PPP performance values – First Stage

	Average PPC	Average rolled PPC	Sigma Level
Tower 1			
O activities	48.24%	5.33%	2.52 σ
G activities	51.07%	6.77%	2.57 σ
Tower 2			
O activities	39.18%	1.41%	2.29 σ
G activities	25.40%	2.23%	1.98 σ

PPP performance values obtained during the First Stage and expressed by the different metrics have revealed the following:

- In accordance with the average PPC values obtained, ‘G activities’ had a better performance in Tower 1 with the average PPC of 51.07%. However, in Tower 2 ‘O activities” obtained a higher average PPC value of 39.18% than that for ‘G activities’ which gave the average PPC of 25.40%. Therefore, from the First Stage it was found that there was no clear dominance of better production performance either in ‘G activities’ or ‘O activities’.
- According to rolled PPC values obtained, ‘G activities’ achieved the higher performance in both Towers. That means ‘G activities’ had less rework because of incomplete tasks on the previous days. However, the majority achieved by ‘G activities’ over ‘O activities’ was not very significant. Moreover, rolled PPC values were significantly lower than the average PPC values registered. Therefore, from the First Stage, it can be observed that both types of activities had important hidden work or rework related to incomplete activities in previous days, while ‘G activities’ achieved a slightly better production performance than ‘O activities’.
- In line with the Sigma Levels obtained, it is appreciated how these values coincided with the average PPC values in determining ‘G activities’ with better performance in Tower 1 and ‘O activities’ in Tower 2. Therefore, Sigma Level values obtained in First Stage have evidenced the accuracy of the Sigma Level metric to reflect the PPP performance and validated its use for benchmarking purposes. For instance, based on the Sigma Levels Scale proposed by Harry and Schroeder (2006), the PPP performance achieved in the First Stage is classified as an ‘Industry average’ process.

- Moreover, according to the 'Implementation Project Charter' of PLAN-SB developed in Section 5.1.1.5, it is interesting to notice that 'Implementation team members' perceived average PPC values ranging from 50% to 70% under the original PPP. However, PPC values perceived from the 'Implementation team members' do not correspond to those obtained during the First Stage as seen in Table 7.1, evidencing the poor accuracy of their perceptions about the PPP performance.

7.3 Discussion on the findings from the Second Stage of PLAN-SB implementation

This section discusses the findings from the Second Stage of PLAN-SB implementation. This stage was divided into two main steps, namely Analysis step and Improve step with the purpose to define the areas to be improved in the PPP, this leads to proposing and improving the PPP.

7.3.1 Analysis Step

It is the purpose of this section to discuss the main findings obtained during the Analysis step. The Analysis step from the implementation of PLAN-SB had the main purpose of identifying the critical areas for improvement in the PPP of Project SB-T2. This was conducted by analyzing the reasons for non-completion (Reasons-NC) of activities with higher frequency and Reasons-NC causing special variations in the workflow. The root causes corresponding to the Reasons-NC with higher frequency were also identified.

7.3.1.1 Discussion on the reasons behind activities incomplete (Reasons-NC) before the improvement of the PPP

In this section the findings obtained related to the reasons causing more activities incomplete before the improvement of the PPP are discussed. From the Reasons-NC collected during the First Stage and by the use of Pareto Charts, the Reasons-NC with higher frequency in 'G activities' and 'O activities' were identified in Section 6.4. The Reasons-NC identified are presented in Table 7.2 and from this information the following has be found:

Table 7.2 Reasons-NC with higher frequency – First Stage

	Reason-NC	
	T1	T2
'O activities'	(10) (8) (3)	(10) (8) (13) (3)
'G activities'	(10) (3) (8)	(10) (8) (3)(2)

- It was found that in the First Stage, 80% frequency causes for the incompletion of activities for 'O activities' were No. (10), (8), (13) and (3) Reasons-NC for both Tower 1 and 2, and that for 'G activities' were No. (10), (8), (3) and (2) Reasons-NC for both Tower 1 and 2. Sharing in common Reasons-NC (10), (3) and (8).
- In the case of Reason-NC (10), representing 'Lack of continuity or prerequisite work not completed', this was the Reason-NC that caused most of the incomplete activities in both Towers. 'Lack of continuity' means that an activity could not be executed due to work that needs to be

completed before. Therefore, having high frequency of this particular Reason-NC suggests two things: (1) activities with an important delay because constraints for execution were not eliminated and consequently these activities are affecting the following activities, and (2) bad quality production plans assigning activities which pre-requisite work is incomplete or not likely to be completed by the time the activity should start. In the case of Reason-NC (8) representing 'Moves to other work area' and Reason-NC (3) representing 'waiting for workers/tools/equipment', these two reasons were the second and third reasons with higher frequency respectively. The high frequency of these two Reasons-NC was found to be related to an increased demand of workers, materials and equipment in the transition from superstructure works to the activities related to the building façade, architectural finishing and services installations. Activities related to the superstructure of the Towers were characterized for being more repetitive, with fewer procedures and requiring less quantity of workers than building façade, architectural finishing and services installations related activities. Thus, the increased demand of workers, materials and equipment evidenced a poor quality PPP provoking an excessive movement of workers from Tower 2 to Tower 1, and vice versa. The increased demand for workers, materials and equipment also affected the lack of certainty of when and where materials and equipment should be administrated.

- It was also found that Reason-NC (2) representing 'Waiting for materials from supplier' was a reason for incomplete activities with high frequency only in 'G activities'. This finding confirms what has been stated by Riley

(2004), Glavinich (2008) and Kibert (2008) who argued that resources procurement for sustainable buildings such as green materials affect the sequencing of activities as well as activity timing.

7.3.1.2 Discussion on the reasons behind special variations in the workflow before the improvement of the PPP

Variability in the workflow is inherent to any process and this can be attributed to either common causes or special causes as discussed in Section 5.2.1.2. It is the purpose of this section to discuss the findings derived from special variations identified in the workflow before the improvement of the PPP. The Reasons-NC causing special variation in the workflow were as follows:

1. Reasons-NC causing special variation in 'G activities' were: (2), (3) and (10).

2. Reasons-NC causing special variation in 'O activities' were: (3), (10) and (13).

- It was found that 'G activities' and 'O activities' shared in common Reasons-NC (10) and (3) as special causes related to the variability in the workflow. It is interesting to notice that these Reasons-NC were also identified in the Pareto Charts as the ones with higher frequency in Section 6.4. Such facts revealed that Reasons-NC (10), (3) not only represented the causes with higher prevalence in the process but also provoked the variability in the workflow.
- It was also found that Reason-NC (2) representing 'Waiting for materials from supplier' previously identified as highly frequent reason in 'G

activities', it is also a reason causing special variations in the workflow but only in 'G activities'. This Confirms a strong relation between 'G activities' incomplete and materials unable to be delivered by the supplier on time.

7.3.1.3 Discussion on the main causes behind Reasons-NC with higher frequency and causing special variations

It was discussed in Section 5.2.1.3 that the Reasons-NC identified as causing majority of activities incomplete and special variations are just the effect of root causes. Thus, a truly improvement could only be achieved by identifying and eliminating the root causes in order to lead to the prevention from the recurrence of the same Reasons-NC. In this content, Cause and Effect Diagram analysis was used to identify the main causes related to the Reasons-NC with higher frequency in Project-SB-T2 during the First Stage. The findings obtained from the identification of the causes behind Reasons-NC with high frequency were:

- Planning, Materials and Management were the most common general causes identified according to Figures 5.11, 5.12 and 5.13.
- Under the Planning category, causes such as inappropriate review process, errors and omissions, unrealistic production plans, poor coordination, poor communication and poor document control were found. The identification of Planning as a main cause behind the Reasons-NC with higher frequency contributed to the justification for the need of the improvement of the PPP in Project SB-T2.
- Under the Materials category, causes such as untimely deliverables, scarce availability of special materials, non-compliance of materials with

specifications, materials not in the right place when needed were found. The identification of Materials as a main cause behind the Reason-NC (10) 'Lack of continuity' and Reason-NC (8) 'Move to other work areas' was an interesting finding, since it was found in the previous section that suppliers experienced difficulties to deliver materials on time when these were related to 'G activities'. Consequently, it can be argued that 'G activities' have also contributed to the high frequency of 'Lack of continuity' and 'Move to other work areas'.

- Under the category of Management, causes such as bad decisions, unpredictable, poor skill and poor leadership were found. The identification of Management as a main cause suggests its relation to poor quality production plans for the following reason: good management needs accurate information in order to take good decisions, therefore, if production plans cannot provide accurate information, bad and unpredictable decisions could be expected. For instance, bad decisions were found in the continuous relocation of crews from one tower to another and the uncertainty of where and when materials needed to be administrated.

7.3.2 Improve Step

It is the purpose of this section to discuss the main findings obtained during the Improve step. The Improve step from the implementation of PLAN-SB had the main purpose of proposing alternative processes towards the improvement of the PPP in Project SB-T2. An improved PPP was implemented and production performance data and reasons for non-completion (Reasons-NC) of activities were collected during the Second Stage. This information was used for obtaining PPC and rolled PPC values and Sigma Levels in order to verify if improvements were achieved after the implementation of the improved PPP.

7.3.2.1 Discussion on the findings from the PPP performance measurement results after improvement actions

From the data obtained in the Second Stage after the implementation of the improved PPP, the PPC, rolled PPC values and Sigma Levels were calculated for both towers and for both types of activities in Sections 6.3.2 and 6.6 respectively. The values obtained are contained in Table 7.3 for discussion.

Table 7.3 PPP performance values – Second Stage

	Average PPC	Average rolled PPC	Sigma Level
Tower 1			
O activities	55.34%	4.77%	2.66 σ
G activities	55.73%	4.74%	2.67 σ
Tower 2			
O activities	60.44%	7.21%	2.68 σ
G activities	57.72%	4.47%	2.67 σ

PPP performance values obtained during the Second Stage and expressed by the different metrics have revealed the following:

- After the implementation of the improved PPP, a more similar performance between Tower 1 and Tower 2 was found compared to the

First Stage performances. This is explained for the higher improvements achieved in Tower 2 in both groups of activities. ‘G activities’ going from and average PPC of 25.40% in the First Stage to 57.72% in the Second Stage, reaching an improvement rate of 127.24%. And, ‘O activities’ from 30.18% to 60.44% average PPC, obtaining an improvement rate of 54.26%. A similar production performance in the two Towers was an important achievement since joint milestones existed between the towers. Therefore, the delay of one Tower could compromise the progress of the other one.

- It was also found that ‘G activities’ in Tower 2 had the greatest improvement after the implementation of the improved PPP, going from an average PPC of 25.40% in the First Stage to 57.72% in the Second Stage. Moreover, it was found that Reasons-NC frequency reductions related to improvements in Tower 2 during the Second Stage were Reasons-NC (3), (10), (6) and (7) as seen in Section 5.2.2.4. Therefore, it can be implied that it is these Reason-NC to lead to such improvement in ‘G activities’. In the case of Reasons-NC (10) and (3), these Reasons-NC were highly frequent in both ‘G activities’ and ‘O activities’ during First Stage and Second Stage. Therefore, a reduction in their frequency could have resulted in an improvement in both types activities. However, Reason-NC (7) ‘Rework resulted from site errors’ had more relation with ‘G activities’ as seen in Table 6.6. Thus, it is suggested that the reduction of frequency of Reason-NC (7) had relation with the performance improvement of ‘G activities’ during the Second Stage.

- According to the rolled PPC values obtained, it was found that these values did not increase much. It suggests that in the short term the improved PPP helped to improve the reliability of production plans only in weekly basis reflected in the achievement of higher weekly PPC values, but the production plans were still highly unreliable in daily basis (i.e. important hidden work or rework related to incomplete activities in previous days still existed).
- In line with the Sigma Levels obtained, it was found that the value with the greatest improvement from First Stage to Second Stage was the one of 'G activities' in Tower 2. Moreover, Sigma Levels determined the better performance of 'G activities' in Tower 1 and 'O activities' in Tower 2. Such evaluations of Sigma Values coincided with the ones of average PPC.

7.3.2.2 Discussion on the reasons behind activities incomplete after the improvement of the PPP

In this section the findings obtained related to the reasons behind activities incomplete after the improvement of the PPP are discussed. From the Reasons-NC collected during the Second Stage and by the use of Pareto Charts, the Reasons-NC with higher frequency in 'G activities' and 'O activities' were identified in Sections 6.4. The Reasons-NC identified are presented in Table 7.4 and from this information the following has be found:

Table 7.4 Reasons-NC with higher frequency and most important increments/decrement in Second Stage

	Reason-NC	
	T1	T2
'O activities'	(10) (8) (2) (3)(11)	(10) (2) (3) (8)(1)(4)
'G activities'	(10) (8) (3) (2)(7)(1)	(10) (3) (2) (8)(7)(11)
Higher decrements in frequency	(10) (3) (8)	(10) (8) (3)
Higher increments in frequency	(7) (2)	(7) (2)
Related to major constrains eliminated by improved PPP	(10) (3) (8)	(10) (3) (8)

- It was found an important decrement in the frequency of Reasons-NC (10), (3) and (8) in both towers, which were the same Reasons-NC resulting with the higher frequency during the First Stage. And, it is observed from Table 7.4 that these Reasons-NC were also related to major constraints eliminated by the improved PPP. Therefore, the improvements achieved in PPC values due to the reduction of frequencies of the Reasons-NC (10), (3) and (8) can be attributed to the improved PPP.
- It was also found that the reduction in frequency of Reasons-NC (10), (3) and (8) evidenced some other Reasons-NC causing 'G activities' or 'O activities' incomplete. For instance, Reason-NC (4) representing 'Lack of access' showed up as highly frequent in 'O activities', while Reason-NC (7) representing ''Rework resulted from site errors' in 'G activities'. In the case of 'O activities', besides Reason-NC (4), it was also found that Reason-NC (11) representing 'Overcrowded working areas' was counted as one of the reasons causing special variations in their workflow as seen in Table 6.8. Both Reasons-NC (4) and (11) related to the constraint 'Space' as seen in Table 5.9. Therefore, the high frequency of these

Reasons-NC suggest a deficiency in the improved PPP for helping to detect and eliminate constraints related to 'Space' issues from activities. In the case of 'G activities', Reason-NC (7) representing 'Rework resulted from site errors' was both highly frequent and also responsible for special variations in the workflow of 'G activities'. Reworks related to site errors during the Second Stage were mainly prevalent in 'G activities' related to the 'building services installations' and 'architectural finishing works' including kitchen appliance installation, sanitary fitting installation and timber flooring. Therefore, the high frequency of Reason-NC (7) suggests the inexperience of workers when working with special requirements by 'G activities' causing important reworks and leading to delays in the project.

- Another finding was that not all Reasons-NC had decrements in frequency after the application of the improved PPP. For instance, Reason-NC (7) and (2) increased their frequencies in 600% and 77.78% respectively in 'G activities'. This finding confirms the strong relation of 'reworks resulted from site errors' and 'waiting materials from supplier' as reasons for no completing 'G activities' as scheduled. Therefore the increment of Reasons-NC (7) and (2) could also be related to the increment in number of 'G activities' from First Stage to Second Stage as seen in Table 6.1.
- Moreover, it was also revealed that Reason-NC (7) representing 'Rework resulted from site errors' was the only one with increment in frequency during the Third Stage. In fact, this Reason-NC was also reported frequency increment in the Second Stage, but mainly affecting 'G activities'. In the Third Stage it is appreciated that the high frequency of

Reason-NC (7) started to be affecting 'O activities' too. However, the frequency increment was much higher in 'G activities' than in 'O activities' as can be seen in Table 6.7. The increment in frequency of Reason-NC (7) can be attributed mainly to two causes: (1) an important root cause related to poor skilled workers unable to effectively meet the requirements of 'G activities', and (2) the difficulties to detect and eliminate constraints in the improved PPP related to poor skilled workers in order to avoid rework related to site errors.

7.4 Discussion on the findings from the Third Stage of PLAN-SB implementation

This section discusses the findings from the Third Stage of PLAN-SB implementation. This stage includes a single step, namely the Control step, and it had the purpose to demonstrate if the improvements achieved during the Second Stage were maintained during the Third Stage of PLAN-SB implementation.

7.4.1 Control Step

It is the purpose of this section to discuss the main findings obtained during the Control step. The Control step from the implementation of PLAN-SB had the main purpose of exploring in what extent the improvements achieved by the improved PPP were controlled through time and whether there was a continuous improvement. Similarly as in previous stages, production performance data and reasons for non-completion (Reasons-NC) of activities were collected during the Third Stage. This information was used for obtaining PPC and rolled PPC values and Sigma Levels in order to compare them with those values obtained in the Second Stage and be able to verify if improvements were maintained during the Third Stage.

7.4.1.1 Discussion on the findings from the PPP performance measurement results during the Control step

From the data obtained in the Third Stage, the PPC, rolled PPC values and Sigma Levels were calculated for both towers and for both types of activities in Sections 6.3.3 and 6.6 respectively. The values obtained are contained in Table 7.5 for discussion.

Table 7.5 PPP performance values – Third Stage

	Average PPC	Average rolled PPC	Sigma Level
Tower 1			
O activities	76.91%	20.05%	3.20 σ
G activities	70.47%	13.25%	3.06 σ
Tower 2			
O activities	81.34%	24.94%	3.30 σ
G activities	67.32%	9.35%	2.99 σ

- From the data presented above it was confirmed that improvements obtained during the Second Stage were not only maintained but also improved in the Third Stage. For instance, it is observed that ‘O activities’ in Tower 2 achieved its highest average PPC value (81.34%) during the Third Stage.

- In fact, it is observed that in this Stage ‘O activities’ obtained the higher average PPC values in both Towers. This is the first time that the higher average PPC values are corresponding to a single type of activities. Consequently, it can be assumed that PLAN-SB helped to improve the performance of ‘O activities’ in a greater extent than that to the performance of ‘G activities’. However, ‘G activities’ also achieved important improvements. For instance, it is observed in Table 6.9 that ‘G activities’ achieved its highest improvement from First Stage to Second Stage with an improvement rate of 34.84%, which also accounted as the highest improvement rate in both type of activities during the implementation of PLAN-SB.
- Rolled PPC values also reached their highest values during the Third Stage in both types of activities and in both Towers. These results suggest that the improved PPP helped in the long term to gradually improve the reliability of production plans to the extent of achieving higher reliability in daily basis. This achievement was obtained by reducing the rework related to incomplete activities in previous days. This finding is confirmed by the important reduction of frequency of Reason-NC (10) representing ‘Lack of continuity’ achieved through the three stages of PLAN-SB implementation as presented in Table 6.7.
- According to the Sigma Levels obtained and based on the Sigma Levels Scale proposed by Harry and Schroeder (2006), the highest Sigma Level achieved during the implementation of PLAN-SB of 3.30σ belongs to ‘O activities’ and is considered as an ‘Industry average’ process. However, as discussed in Section 5.3.1.3, it should be recognized that high Sigma

levels in Construction Industry related processes would be very difficult to achieve because of the uniqueness nature of its projects generating high number of uncertainties. In fact, the Sigma Levels which were obtained before the application of the improved PPP (i.e. 1.98σ, 2.29σ, 2.52σ, and 2.57σ as introduced in Table 6.9) can be compared with other processes such as the one related to internal finishing works in public housing projects in Singapore with a 2.66σ (Han et al. 2008) and to the assembling process in a construction project building power transmission lines with a 1.41σ (Pheng and Hui 2004). Then it is observed that they were about in the same Sigma Level. Therefore, the achievement of a 3.30σ Sigma Level in 'O activities' and 3.06σ Sigma Level in 'G activities' can be considered as an important improvement in the PPP of Project SB-T2.

7.4.1.2 Discussion on the variability results of the PPP after the implementation of PLAN-SB

Reduction of variability is an important sign of improvement in the reliability performance of a production process as suggested by previous studies (Thomas et al., 2002; Gonzalez et al., 2008). Therefore, it was investigated in what extent the variability in the PPP was reduced through the implementation of PLAN-SB. It was found that variability gradually decreased over the three stages of PLAN-SB implementation, as can be appreciated in Tables 6.2, 6.3 and 6.4. When the variability decreased from Stage to Stage, average PPC values increased. Therefore, these findings help to confirm Proposition 2 of this research, which states that a production planning system based in Lean Construction Principles and Six Sigma methodology (i.e. PLAN-SB) can conduce to more reliable production plans.

7.4.1.3 Discussion on the reasons behind activities incomplete during the Control Step

In this section the findings obtained related to the reasons causing more activities incomplete during the Control step of PLAN-SB implementation are discussed. From the Reasons-NC collected during the Third Stage and by the use of Pareto Charts the Reasons-NC with higher frequency in 'G activities' and 'O activities' were identified in Section 6.4. The Reasons-NC identified are presented in Table 7.6 and from this information the following has be found:

Table 7.6 Reasons-NC with higher frequency and most important increments/decrement in Third Stage

	Reason-NC	
	T1	T2
'O activities'	(7) (2) (10) (3)(4)(11)	(10) (4) (2) (3)(7)
'G activities'	(10) (2) (3) (7)(8)(11)	(10) (4) (7) (2)(3)
Higher decrements in frequency	(10) (8) (2)	(10) (8) (2)
Higher increments in frequency	(7)	(7)
Related to major constrains eliminated by improved PPP	(10)(2)(8)(3)	(10)(2)(8)(3)

- From the information presented above, it was found an important decrement in the frequency of Reasons-NC (10), (8) and (2). In fact, Reasons-NC (10) and (8) were also the ones with the most important decrements after the application of the improved PPP as appreciated in Table 6.7. Moreover, it was found that Reasons-NC (10), (8) and (2) were also related to the major constraints eliminated by the improved PPP. Therefore, the improvements achieved in PPC values due to the reduction of frequencies related to these Reasons-NC can be attributed to the improved PPP. In the case of Reason-NC (8) representing ‘Move to other work areas’, the reduction in frequency of this reason is related to the identification of the constraint ‘Change priority’ from activities, and its elimination is mainly attributed to the opportunity to communicate this change in priority on time (i.e. before or during the General Coordination Meetings). In the case of Reason-NC (2) representing ‘waiting for materials from supplier’, its improvement is related to the identification of the constraint ‘Materials’ from activities, and its elimination is attributed to the prompt detection of lack of enough materials for executing an activity and/or the prompt advise from the supplier of the inability to provide the materials on time. Therefore, reductions in frequency of Reasons-NC (8) and (2) can be attributed to the tools used by the improved PPP in the ‘General Coordination Meeting’. These tools include, Engineering Lookahead Schedule Sheet (ELSS) and Screening Activity Sheet (SAS). The tools helped to enhance the communication and coordination among project team members, sub-contractors, suppliers and consultants in the PPP and allowed the prompt detection and elimination of constraints from activities.

7.5 Discussion on the evaluation survey of the improved PPP

As introduced in Chapter 3, an evaluation survey was proposed in this research for examining in what extent the 'implementation team members' and those involved in the PPP perceived benefits from the application of an improved PPP obtained from the implementation of PLAN-SB. In this section, results of the evaluation survey on the improved PPP are obtained from the implementation of PLAN-SB in Project SB-T2, and these results are discussed in this section.

After the implementation of PLAN-SB in project SB-T2, those project team members who were involved in the PPP and participated in the 'General Coordination Meetings' were asked for their opinion on the perceived improvements after the application of the improved PPP. For collecting the data in a systematic way, a questionnaire was prepared containing 8 different statements from where the project team members were asked to judge in a likert scale from 1 to 5 the level of agreement in relation with the statements. The 8 statements were proposed in joint collaboration with key implementation team members regarding issues that were considered important to be evaluated according to expected areas with improvement after the application of the improved PPP and its further adoption. The questionnaire is presented in Appendix G. The participants in the survey were: 10 project team members working for the main contractor (i.e. Contractor X) including the implementation team members as introduced in the Project Charter in Table 5.2, 5 subcontractors, 2 consultants and 2 suppliers. The mean values of the answers were used to judge whether project team members felt the same with regard to the issues raised in the given question and these are contained in Table 7.7.

Table 7.7 Summary of the survey results on the evaluation of the improved PPP

Questions		Mean	Standard deviation	Agree/Disagree the issues in the given questions
No.	Content			
Q1	The availability of data was improved	3.95	0.78	Agree
Q2	The decision-making in the planning process was improved	3.63	0.50	Agree
Q3	The method produced benefits	4.26	0.45	Agree
Q4	A number of key gaps in my organization's ability to have more reliable plans were identified	3.47	0.84	Neutral
Q5	The method helped me clarify my understanding of interagency roles and responsibilities of parties during the production planning process	3.74	0.56	Agree
Q6	The method allowed me to have a greater awareness of the problems, needs, and concerns of other project parties	4.47	0.51	Agree
Q7	It was laborious to work according to the method	3.05	0.62	Neutral
Q8	The method should be used in the next project	3.53	0.61	Agree

5: Strongly Agree, 4: Agree, 3: Neutral, 2: Disagree, 1: Strongly Disagree

Table 7.7 indicates that participants agreed with most of the statements. The results showed that the statement (Q6) 'the method allowed me to have greater awareness of the problems, needs and concerns of other project parties' was the one the participants agreed the most with. As mentioned earlier, reductions of frequencies of Reasons- NC such as (8) and (2) after the application of the improved PPP were perceived to be reduced mainly for the enhancement of communication and coordination among project team members, subcontractors and suppliers in the ‘General Coordination Meetings’. Therefore, the agreement with the statement (Q6) provided positive evidence to support that the improved PPP helped to overcome the problems of communication and coordination among project team members during the PPP.

Results also revealed that participants agreed with both statements ‘ the availability of data was improved’ and ‘the decision-making in the planning process was improved’. This suggests a perceived improvement in the areas of ‘Planning’ and ‘Management’ which major problems include poor document control, unpredictable and bad decisions, inappropriate review process, as seen in Figures 5.11, 5.12 and 5.13. Moreover, the reduction in frequency of Reasons-NC (10), (3) and (8) after the application of the improved PPP supports this improvement perceptions by the participants since ‘Planning’ and ‘Management’ were found as the main causes of occurrence of these Reasons-NC as also seen in Figures 5.11, 5.12 and 5.13.

Participants did not agree with all statements. For instance, they did not agree with statements (Q4) ‘A number of key gaps in my organization’s ability to have more reliable plans were identified’. However, for (Q4) statement it was also appreciated that the standard deviation from the responses was the highest obtained in this survey, which means that the perceptions of the participants could have varied from disagreement (2) to agreement (4) but the mean value resulted as Neutral (3). By analyzing the participants’ responses on relation to (Q4), it was found that suppliers and consultants were the ones that manifested disagreement or neutral opinion in this statement, while participants from the main contractor and subcontractors manifested agreement and even strongly agreement with (Q4). Therefore, the opinions of the participants suggest that the implementation of

PLAN-SB influenced the planning practice of Contractor X and subcontractors in a greater extent than that in suppliers and consultants.

Moreover, participants neither agreed with the statement (Q7) ‘It was laborious to work according to the method’ which revealed that in average participants did not consider laborious to work according to the improved PPP, while they found that the improved PPP produced benefits according to their opinions in (Q3) and they think it should be used in the next project as they opined in (Q8).

Finally, from the above analysis it can be concluded that participants perceived improvement from the implementation of PLAN-SB in particular from the application of the improved PPP. These results echoed the improvements encountered and discussed in previous sections in this Chapter.

Chapter 8

Conclusions

CHAPTER 8: CONCLUSIONS

8.1 Introduction

This chapter presents summaries and conclusions of this study with reviewing the research objectives and research propositions including how the research tasks are defined. Conclusions are made to each stage of the research. The significance and contribution of the research to knowledge, limitations of the study and recommendations for future research are also presented.

8.2 Review of research objectives

The overall aim of this research is to evaluate the performance of the Production Planning Process (PPP) with incorporating sustainability attributes and to propose a system for improving the quality of production planning in construction process when implementing and delivering sustainable building projects. The focus is given on sustainable building projects because of the promotion of sustainable construction and the increase of the adoption of the practice. Sustainable buildings have been already widely adopted, even predicted to represent 20-25 % of new commercial and institutional construction works in the world by 2013 (Han et al. 2008). However, the current building delivery processes are developed best suitable for conventional types of buildings. Previous studies suggest that these traditional building delivery processes are unresponsive to the needs of sustainable building projects (Lapinski et al. 2005). These processes are frequently associated with wasteful rework, delays, changes, and overproduction (Horman et al. 2004). Process waste can both undermine the achievement of sustainable outcomes and limit the business performance for sustainability (U.S.

GSA, 2004; Lapinski et al. 2006). These difficulties have been manifested in making production plans less reliable and with greater variability, which contribute to prolonging cycle times and decreasing system throughput by increasing the amount of waste in a process. These understandings inspired the ambition of applying the success experience of Lean Construction and Six Sigma in reducing waste and improving process performance in complex construction projects. Accordingly, this research proposed the use of Lean Construction principles and Six Sigma methodology to overcome the problems currently encountered in the implementation and delivery of sustainable building projects from the perspective of the production planning process.

The literature review examined the sustainable building practice, the current construction planning and production planning process, Lean Construction and Six Sigma methodology. The understanding on the existing studies leads to the formulation of the research objectives for this study. These objectives include: (1) to measure the production performance of activities with relation to sustainability attributes and compare with those without relation; (2) to evaluate the extent to which the use of Lean Construction and Six Sigma can improve effectiveness and efficiency in the PPP during the implementation of sustainable building projects; and (3) to identify the main causes behind the effective and efficient achievement of sustainability goals during construction stage in sustainable building projects. A methodology comprising different research methods including direct observations, interviews and action research was constructed to achieve these objectives. The completion of these research objectives was achieved through four specific tasks:

- *The first task is to develop a production planning system that can be used as a tool to investigate the effect of using Lean Construction principles and Six Sigma methodology in sustainable building projects.* According to the review on sustainable building practice, the current construction planning and production planning process, Lean Construction and Six Sigma methodology, a production planning system (i.e. PLAN-SB) was developed in Chapter 4 as a tool to investigate the effect of using Lean Construction principles and Six Sigma methodology on the implementation of sustainable building projects.
- *The second research task is to develop a framework of how the proposed production planning system can be implemented in sustainable building projects.* The implementation framework is a principal guidance. It was developed based on the generic frameworks DMAIC (Define, Measure, Analysis, Improve and Control) and IPO (Input, Process and Output) for implementing PLAN-SB in sustainable building projects.
- *The third research task is to measure, analyze and control the effects of using Lean Construction principles and Six Sigma methodology.* In order to complete this task, action research method was used in the form of a case study for measuring, analyzing and controlling the effects of PLAN-SB implementation. The research outcomes from conducting this task are presented in Chapter 5.
- *The fourth research task* is to *record the causes affecting the production performance of activities and identify the ones related to sustainability attributes of the project.* This task was completed by a comparative analysis for identifying the causes affecting production performance of

activities with direct relation to sustainable deliverables (i.e. 'G activities') and those with no direct relation (i.e. 'O activities'). The outcomes of this task are presented in Chapter 6.

8.3 Research Conclusions

8.3.1 Advanced understandings from literature review

The literature review was conducted with focusing on sustainable building practice, the current construction planning and production planning process, Lean Construction and Six Sigma methodology. The review leads to the major understandings: (1) the current production planning practices has limitation for application for delivering sustainable buildings and are not enabling sustainability goals to be achieved efficiently and effectively. (2) Lean Construction principles can lead to a production planning process more efficient and can integrate effectively client values (i.e. sustainability). (3) Six Sigma methodology can conduce to a more effective production planning process and assist to deliver high quality plans. Based on these understandings, it is proposed that the combined use of Lean Construction principles and Six Sigma methodology can improve the efficiency and effectiveness in the implementation and delivery of sustainable building projects.

The examination of the characteristics of the sustainable building practice has led to determining what types of metrics and tools from Lean Construction and Six Sigma are appropriate for defining, measuring, analyzing, improving and controlling the PPP in sustainable building projects. The application of these metrics and tools was analyzed by establishing the following propositions:

- The PPP should be documented and defined for its analysis. The tools selected for defining the PPP were: Organizational Structure Chart, SIPOC (Supplier, Inputs, Process, Outputs, Customer) Diagram, Flow Diagram and Project Charter.
- The production planning process should be measured in order to investigate the effect of implementing the proposed production planning system (i.e. PLAN-SB). The metrics selected for measuring the performance were: Percent Plan Complete (PPC), rolled PPC and Sigma Level.
- The causes affecting the performance of the PPP should be investigated in order to define the areas for improvement. The tools selected for analyzing the causes were: Pareto Chart, Cause and Effect Diagram and P-Chart.
- The improvement of the PPP performance could be achieved by changing from the traditional Push Planning System to Pull Planning System.
- Reduction of variability in the workflow is a sign of reliability of production plans.

According to the criteria identified above, a production planning system named PLAN-SB was developed during this research. PLAN- SB can provide the metrics, tools and an implementation framework for improving the PPP in sustainable building projects. Details of PLAN-SB are presented in Chapter 4.

8.3.2 The results from the implementation of PLAN-SB

In the implementation of PLAN-SB, production performance measurements were taken in two types of activities, namely ‘G activities’ (i.e. activities with direct relation to sustainable deliverables) and ‘O activities’ (i.e. activities with no direct relation to sustainable deliverables). The classification of ‘G activities’ and ‘O activities’ was made with the main purpose of exploring the differences in their production performances and causes affecting their production performances. For comparison analysis, production performance measurements were taken under the traditional PPP and under the improved PPP which is generated in PLAN-SB. Causes affecting the production performance of activities and variability in the workflow (Reasons-NC) were identified. Therefore, conclusions from the implementation of PLAN-SB are drawn in three aspects: outcomes from the application of the traditional PPP, outcomes from the application of the improved PPP, and general conclusions.

The application of the traditional PPP

- Production performances obtained from ‘G activities’ and ‘O activities’ under the traditional PPP revealed a poor performance in both types of activities, completing in average less than 50% of activities planned. Moreover, it was found that there was not a clear dominance of better performance either in ‘G activities’ or ‘O activities’. Similarly, rolled PPC values revealed that both types of activities had important hidden works or reworks related to incomplete activities in previous days, while ‘G activities’ achieved a slightly better performance than ‘O activities’. Therefore, it can be concluded that the traditional PPP used in the case under study was unable to generate reliable production plans, which led to reducing the production performance of activities.

- The analysis on the reasons for non-completion of activities (Reasons-NC) under the traditional PPP revealed high frequency causes affecting the production performance of activities. These causes include: 'prerequisite work not completed', 'changes in priority provoking movements from one working area to another' and 'lack of workers'. However, a cause with more relation to 'G activities' was 'waiting for materials from supplier'. Therefore, it can be concluded that while major problems in the production performance of "G activities' and 'O activities' existed due to common causes, 'waiting for materials from supplier' was mainly caused for those activities with relation to sustainable deliverables.
- From the production performances of activities obtained from the application of the traditional PPP, significant variability was found in the production performance of activities. Such variability in the performance revealed poor reliability of production plans generated under the traditional PPP. Moreover, it was found that a frequent cause of variability was 'waiting for materials from supplier' having more relation with 'G activities' than 'O activities'. Therefore, it can be concluded that activities related to sustainable deliverables had greater impact on the variability of the workflow in the project under study.

The application of the improved PPP

- The application of the improved PPP, which is generated from the implementation of PLAN-SB, resulted in significant increase in the percentage of activities completed as planned, reaching values above 80%.

Therefore, it can be concluded that the implementation of PLAN-SB effectively improved the production performance, leading to more reliable production plans and the improvement of production performances of activities.

- From applying the improved PPP of PLAN-SB, it was observed that ‘O activities’ obtained better production performances than ‘G activities’. Consequently, it can be concluded that PLAN-SB helped to improve the production performance of ‘O activities’ in a greater extent than the performance of ‘G activities’. By using the improved PPP, the Rolled PPC values also increased importantly in ‘G activities’ and ‘O activities’. Therefore, it can be concluded that the improved PPP helped to improve the reliability of production plans to the extent of achieving higher reliability in daily basis and reducing the rework related to incomplete activities in previous days.
- After the application of the improved PPP, significant decrements in frequency were found to those reasons for non-completion of activities, which were highly frequent under the application of the traditional PPP. These reasons were: ‘prerequisite work not completed’, ‘changes in priority provoking movements from one working area to another’ and ‘waiting for materials from supplier’. Moreover, it was found that these same reasons were also related to the major constraints eliminated from activities by the improved PPP. Therefore, it can be concluded that the improvements in production performance of activities were achieved from the application of improved PPP.

- It was also found that the reasons for non-completion ‘changes in priority provoking movements from one working area to another’ and ‘waiting for materials from supplier’ were mainly related to the root causes in communication and coordination among the main contractor, the subcontractors and the suppliers. Therefore, it can be concluded that reductions in frequency of these reasons for non-completion of activities can be attributed to the tools proposed in the improved PPP for enhancing the communication and coordination among participants in the ‘General Coordination Meeting’.
- Moreover, it was also revealed that the reason for non-completion of activities ‘rework resulted from site errors’ was the only one with increment in frequency after the application of the improved PPP. The frequency increment of this reason was much higher in ‘G activities’ than in ‘O activities’. This increment in frequency was attributed mainly to two causes: (1) an important root cause related to poor skilled workers unable to effectively meet the requirements of ‘G activities’, and (2) the difficulties to detect and eliminate constraints in the improved PPP related to poor skilled workers in order to avoid rework related to site errors.
- The variability gradually decreased after the application of the improved PPP. As the variability decreased through time, the average production performances of activities increased. Therefore, results obtained in this study echoed the findings by others studies concluding that reduction of variability is related to an increase in the reliability performance of a production process.

8.3.3 General conclusions

- There is a need for improving traditional production planning process in order to implement successfully sustainable buildings. PLAN-SB is introduced as an effective system to make this improvement by increasing the reliability of the production planning process. Improvements in production performance of activities are accompanied by more stable and less variable workflow.
- The system PLAN-SB introduced in this study has shown the effectiveness in achieving the improvements in production performance of activities. The analysis of the evidence obtained from the implementation PLAN-SB in this study demonstrate the effectiveness of Lean Construction and Six Sigma methodology in the improvement of the production planning process of sustainable building projects. Consequently, the application of these tools in the system PLAN-SB has improved the efficiency and effectiveness of the implementation and delivery process of sustainable building projects.

8.4 Contribution to knowledge

This research has contributed to the field of knowledge spanning across different areas: construction management, sustainable construction, production management and quality management. This research has explored the application of Lean Construction principles and Six Sigma methodology in a new field: sustainable construction. The main research outcomes include new knowledge on the impact of using Lean Construction principles and Six Sigma methodology in the production planning process for implementing sustainable building projects. The contributions to knowledge can be summarized as follows:

1. The research has successfully developed a system (i.e. PLAN-SB) for the application of Lean Construction and Six Sigma in the production planning process of sustainable building projects. The positive results during this research suggest that Lean Construction and Six Sigma are suitable for improving the reliability of the production planning process in the implementation and delivery of sustainable building projects. The metrics adopted in this research, namely Percent Plan Complete (PPC), rolled PPC, and Sigma Level have also been confirmed as effective performance metrics for the production planning process. Moreover, the use of Organizational Structure Chart, SIPOC Diagram, Flow Diagram and Project Charter in the system PLAN-SB has been confirmed to be effective tools for documenting the production planning process. Therefore, the implementation framework of PLAN-SB provides a useful reference for both researchers and practitioners who would like to implement Lean Construction and Six Sigma in sustainable construction projects.
2. This research has identified the critical areas related to poor production performance of activities related to sustainable deliverables. The areas identified provide valuable references for both researchers and practitioners on where studies and efforts are needed for improving the efficiency and effectiveness in the implementation and delivery of sustainable building projects.

3. This study has contributed to the understanding of the prevalent practice for production planning in sustainable building projects. The findings from the study will be a good resource for future studies in this area.

8.5 Limitations of the study

Three limitations have been outlined as follows:

1. This research is focused on sustainable building projects. This is due to the scarce research conducted in the area of sustainable building delivery processes, in specific, in the area production performance. Although the results can be useful for other types of projects, it is primarily investigated for the sustainable building practice.
2. In the first stage of implementation of PLAN-SB, it is aimed to examine the performance of the original production planning process in practice. However, in order to examine the performance, data collection on the production performance of activities are needed. This data is collected by the 'implementation team members' who are also involved in the production planning process. Since the production performances of activities are known by them during the examination period, this already represents a variable in the original production planning process. This fact may have influenced the process affecting the initial purpose of examining the performance under the original production planning practice.
3. More case studies could be conducted to confirm the effects of Lean Construction and Six Sigma in the production planning process of sustainable construction projects. However, the use of one major project in this study is consistent with the research goal. This research was mainly

concerned with determining the extent to which the adoption of a production planning system based on Lean Construction Principles and Six Sigma methodology is effective and why it is or is not effective.

8.6 Recommendation areas for future research

1. This research focused on one delivery process (i.e. production planning process) of several others in sustainable building projects. Future research can focus on different delivery processes. Some delivery process that can be studied includes: design process, pre-construction process, and construction process.
2. Further development of PLAN-SB is suggested regarding not only the elimination of constraints from activities affecting their production performance but also helping in the definition of strategies for eliminating the root causes generating the constraints. In addition, the development of a software integrating the tools and metrics proposed in PLAN-SB is suggested for speeding up the generation of performance results in order to spend less time in the generation of results and spend more time in their analysis.
3. This research has initiated a study to use Lean Construction and Six Sigma in sustainable building projects. Future research can adopt more tools from Lean Construction and Six Sigma methodology. The combination of the two methods promise to be a very powerful instrument in improving processes in the construction industry.

4. While the scope of this study focus on the improvement of the production performance of sustainable building projects and it is based on measurements related to time, the trade-offs between time, cost and quality are acknowledged. For instance, it has been found that premium costs in sustainable buildings are not only related to more expensive materials and technology but also to delays and rework emerging from ineffective and inefficient delivery processes. Quality standards and especially those related to the sustainability performance of buildings are also related to new requirements and complexities which have been manifested in delays and reworks compromising the estimated delivery time and cost of projects. This study has identified and highlighted such time-cost and time-quality trade-offs and their relevance, however it is beyond the scope of this study their measurement and analysis. Therefore it is considered relevant that future studies address their analysis for further identification of potential areas for improvement in the delivery process of sustainable buildings.

Appendix A

Data collection summary tables - Production performance data

APPENDIX A: DATA COLLECTION SUMMARY TABLES – PRODUCTION PERFORMANCE DATA

Production performance data collected from Tower 1 (First Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 1	30-Mar	17	10	7	10	7	3	7	3	4
	31-Mar	15	10	5	9	6	3	6	4	2
	01-Apr	19	14	5	10	7	3	9	7	2
	02-Apr	18	12	6	11	6	5	7	6	1
	03-Apr	16	10	6	9	5	4	7	5	2
	06-Apr	13	7	6	8	4	4	5	3	2
Week 2	07-Apr	15	8	7	9	5	4	6	3	3
	08-Apr	19	6	13	10	4	6	9	2	7
	09-Apr	19	7	12	10	3	7	9	4	5
Week 3	14-Apr	23	10	13	13	4	9	10	6	4
	15-Apr	21	10	11	12	7	5	9	3	6
	16-Apr	20	8	12	11	4	7	9	4	5
	17-Apr	22	11	11	12	6	6	10	5	5
	18-Apr	21	11	10	13	7	6	8	4	4
	20-Apr	19	8	11	12	5	7	7	3	4
Week 4	21-Apr	17	7	10	11	5	6	6	2	4
	22-Apr	17	9	8	10	7	3	7	2	5
	23-Apr	19	10	9	11	6	5	8	4	4
	24-Apr	18	9	9	11	6	5	7	3	4
	25-Apr	17	10	7	10	7	3	7	3	4
	27-Apr	20	11	9	12	6	6	8	5	3
Week 5	28-Apr	17	9	8	11	6	5	6	3	3
	29-Apr	17	8	9	11	5	6	6	3	3
	30-Apr	19	10	9	12	7	5	7	3	4
	04-May	19	10	9	11	6	5	8	4	4

Production performance data collected from Tower 2 (First Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 1	30-Mar	19	13	6	10	6	4	9	7	2
	31-Mar	17	15	2	10	9	1	7	6	1
	01-Apr	15	13	2	9	8	1	6	5	1
	02-Apr	15	14	1	9	9	0	6	5	1
	03-Apr	18	13	5	9	5	4	9	8	1
	06-Apr	14	11	3	8	7	1	6	4	2
Week 2	07-Apr	11	8	3	7	6	1	4	2	2
	08-Apr	18	7	11	10	3	7	8	4	4
	09-Apr	18	10	8	9	5	4	9	5	4
Week 3	14-Apr	22	7	15	13	3	10	9	4	5
	15-Apr	21	8	13	14	4	10	7	4	3
	16-Apr	18	8	10	10	1	9	8	7	1
	17-Apr	20	12	8	13	6	7	7	6	1
	18-Apr	20	12	8	12	5	7	8	7	1
	20-Apr	19	12	7	9	8	1	10	4	6
Week 4	21-Apr	17	8	9	11	3	8	6	5	1
	22-Apr	19	11	8	12	6	6	7	5	2
	23-Apr	19	13	6	11	7	4	8	6	2
	24-Apr	19	15	4	12	9	3	7	6	1
	25-Apr	19	15	4	12	9	3	7	6	1
	27-Apr	20	13	7	11	6	5	9	7	2
Week 5	28-Apr	19	14	5	12	7	5	7	7	0
	29-Apr	18	13	5	12	7	5	6	6	0
	30-Apr	19	17	2	11	10	1	8	7	1
	04-May	17	13	4	10	7	3	7	6	1

Production performance data collected from Tower 1 (Second Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 6	05-May	16	12	4	8	6	2	8	6	2
	06-May	19	12	7	9	6	3	10	6	4
	07-May	18	14	4	9	7	2	9	7	2
	08-May	15	11	4	7	5	2	8	6	2
	09-May	17	13	4	9	7	2	8	6	2
	11-May	9	3	6	4	1	3	5	2	3
Week 7	12-May	8	3	5	3	1	2	5	2	3
	13-May	8	2	6	4	1	3	4	1	3
	14-May	8	2	6	4	1	3	4	1	3
	15-May	8	2	6	4	1	3	4	1	3
	16-May	7	2	5	3	1	2	4	1	3
	18-May	13	6	7	6	3	3	7	3	4
Week 8	19-May	12	5	7	6	3	3	6	2	4
	20-May	10	4	6	5	2	3	5	2	3
	21-May	13	8	5	7	4	3	6	4	2
	22-May	11	7	4	5	3	2	6	4	2
	23-May	10	6	4	4	2	2	6	4	2
	25-May	13	9	4	7	5	2	6	4	2
Week 9	26-May	12	7	5	5	3	2	7	4	3
	27-May	10	5	5	4	3	1	6	2	4
	29-May	14	8	6	7	4	3	7	4	3
	30-May	11	5	6	5	2	3	6	3	3
	01-Jun	14	8	6	7	4	3	7	4	3
Week 10	02-Jun	16	6	10	9	3	6	7	3	4
	03-Jun	16	7	9	9	4	5	7	3	4
	04-Jun	14	5	9	7	2	5	7	3	4
	05-Jun	16	7	9	9	4	5	7	3	4
	06-Jun	15	5	10	7	2	5	8	3	5
	08-Jun	16	4	12	8	2	6	8	2	6

Production performance data collected from Tower 2 (Second Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 6	05-May	15	13	2	7	6	1	8	7	1
	06-May	17	14	3	8	7	1	9	7	2
	07-May	16	15	1	8	8	0	8	7	1
	08-May	15	9	6	7	4	3	8	5	3
	09-May	16	16	0	8	8	0	8	8	0
	11-May	13	2	11	8	1	7	5	1	4
Week 7	12-May	13	5	8	7	2	5	6	3	3
	13-May	11	3	8	5	1	4	6	2	4
	14-May	12	5	7	6	2	4	6	3	3
	15-May	11	4	7	5	2	3	6	2	4
	16-May	9	2	7	4	1	3	5	1	4
	18-May	11	4	7	5	2	3	6	2	4
Week 8	19-May	11	5	6	5	2	3	6	3	3
	20-May	11	4	7	5	2	3	6	2	4
	21-May	11	4	7	5	2	3	6	2	4
	22-May	10	6	4	5	3	2	5	3	2
	23-May	10	5	5	4	2	2	6	3	3
	25-May	10	5	5	4	2	2	6	3	3
Week 9	26-May	11	7	4	5	3	2	6	4	2
	27-May	9	4	5	4	2	2	5	2	3
	29-May	14	8	6	7	4	3	7	4	3
	30-May	12	5	7	5	2	3	7	3	4
	01-Jun	15	8	7	7	4	3	8	4	4
Week 10	02-Jun	14	5	9	7	2	5	7	3	4
	03-Jun	14	4	10	8	2	6	6	2	4
	04-Jun	13	5	8	6	2	4	7	3	4
	05-Jun	14	5	9	6	2	4	8	3	5
	06-Jun	14	4	10	7	2	5	7	2	5
	08-Jun	14	3	11	6	1	5	8	2	6

Production performance data collected from Tower 1 (Third Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 11	09-Jun	16	5	11	7	2	5	9	3	6
	10-Jun	16	5	11	7	2	5	9	3	6
	11-Jun	16	4	12	8	2	6	8	2	6
	12-Jun	15	6	9	8	3	5	7	3	4
	13-Jun	15	5	10	7	2	5	8	3	5
	15-Jun	10	1	9	4	0	4	6	1	5
Week 12	16-Jun	5	1	4	2	0	2	3	1	2
	17-Jun	8	2	6	4	1	3	4	1	3
	18-Jun	7	2	5	3	1	2	4	1	3
	19-Jun	8	2	6	4	1	3	4	1	3
	20-Jun	7	2	5	3	1	2	4	1	3
	22-Jun	5	1	4	2	0	2	3	1	2
Week 13	23-Jun	10	3	7	4	1	3	6	2	4
	24-Jun	10	4	6	5	2	3	5	2	3
	25-Jun	10	4	6	5	2	3	5	2	3
	26-Jun	10	4	6	5	2	3	5	2	3
	27-Jun	9	2	7	3	0	3	6	2	4
	29-Jun	7	1	6	3	0	3	4	1	3
Week 14	30-Jun	7	1	6	3	0	3	4	1	3
	02-Jul	7	2	5	3	1	2	4	1	3
	03-Jul	7	1	6	3	0	3	4	1	3
	04-Jul	7	2	5	3	1	2	4	1	3
	06-Jul	8	2	6	4	1	3	4	1	3
Week 15	07-Jul	8	2	6	4	1	3	4	1	3
	08-Jul	8	2	6	4	1	3	4	1	3
	09-Jul	8	3	5	3	1	2	5	2	3
	10-Jul	7	2	5	3	1	2	4	1	3
	11-Jul	7	2	5	3	1	2	4	1	3
	13-Jul	7	1	6	3	0	3	4	1	3
Week 16	14-Jul	7	1	6	3	0	3	4	1	3
	15-Jul	7	2	5	3	1	2	4	1	3
	16-Jul	7	2	5	3	1	2	4	1	3
	17-Jul	5	1	4	2	0	2	3	1	2

	18-Jul	5	1	4	2	0	2	3	1	2
	20-Jul	5	2	3	2	1	1	3	1	2
Week 17	21-Jul	5	2	3	2	1	1	3	1	2
	22-Jul	6	2	4	3	1	2	3	1	2
	23-Jul	6	1	5	2	0	2	4	1	3
	24-Jul	6	2	4	3	1	2	3	1	2
	25-Jul	6	2	4	3	1	2	3	1	2
	27-Jul	7	2	5	3	1	2	4	1	3

Production performance data collected from Tower 2 (Third Stage)

	Day	Total Activities Planned	Total Activities Incomplete	Total Activities Complete	O Activities Planned	O Activities Incomplete	O Activities Complete	G Activities Planned	G Activities Incomplete	G Activities Complete
Week 11	09-Jun	14	3	11	6	1	5	8	2	6
	10-Jun	15	5	10	7	2	5	8	3	5
	11-Jun	14	4	10	7	2	5	7	2	5
	12-Jun	12	3	9	5	1	4	7	2	5
	13-Jun	13	6	7	6	3	3	7	3	4
	15-Jun	8	1	7	3	0	3	5	1	4
Week 12	16-Jun	7	2	5	3	1	2	4	1	3
	17-Jun	8	3	5	3	1	2	5	2	3
	18-Jun	8	3	5	3	1	2	5	2	3
	19-Jun	8	3	5	3	1	2	5	2	3
	20-Jun	8	2	6	4	1	3	4	1	3
	22-Jun	6	1	5	2	0	2	4	1	3
Week 13	23-Jun	6	2	4	3	1	2	3	1	2
	24-Jun	5	1	4	2	0	2	3	1	2
	25-Jun	5	2	3	3	1	2	2	1	1
	26-Jun	5	2	3	2	1	1	3	1	2
	27-Jun	5	2	3	2	1	1	3	1	2
	29-Jun	3	0	3	2	0	2	1	0	1
Week 14	30-Jun	3	1	2	1	0	1	2	1	1
	02-Jul	3	1	2	1	0	1	2	1	1
	03-Jul	3	0	3	1	0	1	2	0	2
	04-Jul	3	1	2	1	0	1	2	1	1
	06-Jul	6	2	4	3	1	2	3	1	2
Week 15	07-Jul	5	2	3	2	1	1	3	1	2
	08-Jul	5	1	4	2	0	2	3	1	2
	09-Jul	6	2	4	4	1	3	2	1	1
	10-Jul	5	1	4	2	0	2	3	1	2
	11-Jul	5	1	4	2	0	2	3	1	2
	13-Jul	6	1	5	2	0	2	4	1	3
Week 16	14-Jul	5	2	3	2	1	1	3	1	2
	15-Jul	4	1	3	1	0	1	3	1	2
	16-Jul	4	1	3	1	0	1	3	1	2
	17-Jul	4	1	3	2	0	2	2	1	1

	18-Jul	4	1	3	1	0	1	3	1	2
	20-Jul	4	1	3	1	0	1	3	1	2
Week 17	21-Jul	5	2	3	2	1	1	3	1	2
	22-Jul	5	2	3	2	1	1	3	1	2
	23-Jul	5	1	4	2	0	2	3	1	2
	24-Jul	5	1	4	2	0	2	3	1	2
	25-Jul	5	2	3	2	1	1	3	1	2
	27-Jul	3	0	3	1	0	1	2	0	2

Appendix B

Data collection summary tables – Reasons for non-completion

APPENDIX B: DATA COLLECTION SUMMARY TABLES –

REASONS FOR NON-COMPLETION

Reasons for non-completion from Tower 1 - First Stage

Tower 1

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	0	2	0	0	2
2	Waiting for materials (supplier)	8	0	0	2	2	12
3	Waiting for tools and equipment	23	3	3	13	8	50
4	Lack of access	0	2	1	0	0	3
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	2	0	0	2
8	Moves to other work area	0	6	17	13	9	45
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	21	5	28	25	18	97
11	Overcrowded working areas	4	2	3	3	0	12
12	Inclement weather	0	0	0	0	0	0
13	Other	7	3	2	0	0	12

Tower 1 "O activities"

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	0	0	0	0	0
2	Waiting for materials (supplier)	2	0	0	1	1	4
3	Waiting for tools and equipment	12	1	0	5	4	22
4	Lack of access	0	1	1	0	0	2
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	1	0	0	1
8	Moves to other work area	0	4	12	10	5	31
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	13	2	15	18	13	61
11	Overcrowded working areas	4	1	2	3	0	10
12	Inclement weather	0	0	0	0	0	0
13	Other	4	3	2	0	0	9

Tower 1 "G activities"

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	0	2	0	0	2
2	Waiting for materials (supplier)	6	0	0	1	1	8
3	Waiting for tools and equipment	11	2	3	8	4	28
4	Lack of access	0	1	0	0	0	1
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	1	0	0	1
8	Moves to other work area	0	2	5	3	4	14
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	8	3	13	7	5	36
11	Overcrowded working areas	0	1	1	0	0	2
12	Inclement weather	0	0	0	0	0	0
13	Other	3	0	0	0	0	3

Reasons for non-completion from Tower 2 - First Stage

Tower 2

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	1	3	0	0	4
2	Waiting for materials (supplier)	5	1	3	12	6	27
3	Waiting for tools and equipment	11	3	2	13	8	37
4	Lack of access	0	1	3	0	0	4
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	2	0	0	2
8	Moves to other work area	2	6	15	24	12	59
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	29	10	26	22	16	103
11	Overcrowded working areas	4	1	3	2	1	11
12	Inclement weather	0	0	0	0	0	0
13	Other	28	2	2	0	0	32

Tower 2 "O activities"

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	1	0	0	0	1
2	Waiting for materials (supplier)	1	0	1	5	2	9
3	Waiting for tools and equipment	5	1	1	6	3	16
4	Lack of access	0	1	2	0	0	3
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	1	0	0	1
8	Moves to other work area	2	4	8	14	7	35
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	18	5	11	12	10	56
11	Overcrowded working areas	2	1	2	1	1	7
12	Inclement weather	0	0	0	0	0	0
13	Other	16	1	1	0	0	18

Tower 2 "G activities"

No. ID	Reason for non-completion	Week 1	Week 2	Week 3	Week 4	Week 5	Total
1	Waiting for materials (on site)	0	0	3	0	0	3
2	Waiting for materials (supplier)	4	1	2	7	4	18
3	Waiting for tools and equipment	6	2	1	7	5	21
4	Lack of access	0	0	1	0	0	1
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	0	0	0	0	0	0
7	Changes/redoing work (site errors)	0	0	1	0	0	1
8	Moves to other work area	0	2	7	10	5	24
9	Waiting for information	0	0	0	0	0	0
10	Lack of continuity	11	5	15	10	6	47
11	Overcrowded working areas	2	0	1	1	0	4
12	Inclement weather	0	0	0	0	0	0
13	Other	12	1	1	0	0	14

Reasons for non-completion from Tower 1 - Second Stage

Tower 1

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	3	0	6	0	2	11
2	Waiting for materials (supplier)	6	2	6	4	9	27
3	Waiting for tools and equipment	13	2	0	3	6	24
4	Lack of access	0	0	4	6	0	10
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	4	0	0	0	0	4
7	Changes/redoing work (site errors)	4	0	6	4	0	14
8	Moves to other work area	12	5	5	3	6	31
9	Waiting for information	0	0	3	0	0	3
10	Lack of continuity	16	5	8	9	11	49
11	Overcrowded working areas	6	3	1	4	0	14
12	Inclement weather	0	0	0	0	0	0
13	Other	1	0	0	0	0	1

Tower 1 "O activities"

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	1	0	3	0	1	5
2	Waiting for materials (supplier)	4	1	3	2	6	16
3	Waiting for tools and equipment	8	1	0	1	2	12
4	Lack of access	0	0	2	3	0	5
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	2	0	0	0	0	2
7	Changes/redoing work (site errors)	2	0	3	2	0	7
8	Moves to other work area	6	3	3	2	3	17
9	Waiting for information	0	0	1	0	0	1
10	Lack of continuity	10	3	5	5	5	28
11	Overcrowded working areas	4	1	0	3	0	8
12	Inclement weather	0	0	0	0	0	0
13	Other	0	0	0	0	0	0

Tower 1 "G activities"

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	2	0	3	0	1	6
2	Waiting for materials (supplier)	2	1	3	2	3	11
3	Waiting for tools and equipment	5	1	0	2	4	12
4	Lack of access	0	0	2	3	0	5
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	2	0	0	0	0	2
7	Changes/redoing work (site errors)	2	0	3	2	0	7
8	Moves to other work area	6	2	2	1	3	14
9	Waiting for information	0	0	2	0	0	2
10	Lack of continuity	6	2	3	4	6	21
11	Overcrowded working areas	2	2	1	1	0	6
12	Inclement weather	0	0	0	0	0	0
13	Other	1	0	0	0	0	1

Reasons for non-completion from Tower 2 - Second Stage

Tower 2

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	5	2	5	0	1	13
2	Waiting for materials (supplier)	7	4	5	4	5	25
3	Waiting for tools and equipment	11	4	0	3	5	23
4	Lack of access	1	0	4	6	0	11
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	5	0	0	0	0	5
7	Changes/redoing work (site errors)	6	1	2	4	0	13
8	Moves to other work area	8	5	3	1	3	20
9	Waiting for information	0	0	2	0	0	2
10	Lack of continuity	17	5	8	10	12	52
11	Overcrowded working areas	7	2	0	4	0	13
12	Inclement weather	0	0	0	0	0	0
13	Other	2	0	0	0	0	2

Tower 2 "O activities"

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	3	1	3	0	1	8
2	Waiting for materials (supplier)	4	3	3	3	3	16
3	Waiting for tools and equipment	5	2	0	2	3	12
4	Lack of access	1	0	2	4	0	7
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	3	0	0	0	0	3
7	Changes/redoing work (site errors)	3	1	1	2	0	7
8	Moves to other work area	4	3	2	1	2	12
9	Waiting for information	0	0	1	0	0	1
10	Lack of continuity	9	3	5	5	6	28
11	Overcrowded working areas	4	1	0	2	0	7
12	Inclement weather	0	0	0	0	0	0
13	Other	2	0	0	0	0	2

Tower 2 "G activities"

No. ID	Reason for non-completion	Week 6	Week 7	Week 8	Week 9	Week 10	Total
1	Waiting for materials (on site)	2	1	2	0	0	5
2	Waiting for materials (supplier)	3	1	2	1	2	9
3	Waiting for tools and equipment	6	2	0	1	2	11
4	Lack of access	0	0	2	2	0	4
5	Equipment breakdowns	0	0	0	0	0	0
6	Changes/redoing work (design errors)	2	0	0	0	0	2
7	Changes/redoing work (site errors)	3	0	1	2	0	6
8	Moves to other work area	4	2	1	0	1	8
9	Waiting for information	0	0	1	0	0	1
10	Lack of continuity	8	2	3	5	6	24
11	Overcrowded working areas	3	1	0	2	0	6
12	Inclement weather	0	0	0	0	0	0
13	Other	0	0	0	0	0	0

Reasons for non-completion from Tower 1 - Third Stage

Tower 1

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	2	0	1	0	1	1	0	5
2	Waiting for materials (supplier)	3	2	3	1	2	0	2	13
3	Waiting for tools and equipment	3	3	2	1	0	2	1	12
4	Lack of access	0	1	3	1	3	2	0	10
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	3	0	0	0	0	0	0	3
7	Changes/redoing work (site errors)	4	0	3	2	2	1	2	14
8	Moves to other work area	5	2	1	1	1	0	0	10
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	6	2	2	1	1	1	2	15
11	Overcrowded working areas	1	0	3	1	2	2	2	11
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Tower 1 "O activities"

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	1	0	1	0	1	0	0	3
2	Waiting for materials (supplier)	2	1	2	1	1	0	1	8
3	Waiting for tools and equipment	2	2	1	0	0	1	1	7
4	Lack of access	0	1	2	0	2	1	0	6
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	2	0	0	0	0	0	0	2
7	Changes/redoing work (site errors)	2	0	2	1	2	1	1	9
8	Moves to other work area	3	1	0	1	0	0	0	5
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	3	1	1	1	0	1	1	8
11	Overcrowded working areas	1	0	1	1	1	1	1	6
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Tower 1 "G activities"

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	1	0	0	0	0	1	0	2
2	Waiting for materials (supplier)	1	1	1	0	1	0	1	5
3	Waiting for tools and equipment	1	1	1	1	0	1	0	5
4	Lack of access	0	0	1	1	1	1	0	4
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	1	0	0	0	0	0	0	1
7	Changes/redoing work (site errors)	2	0	1	1	0	0	1	5
8	Moves to other work area	2	1	1	0	1	0	0	5
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	3	1	1	0	1	0	1	7
11	Overcrowded working areas	0	0	2	0	1	1	1	5
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Reasons for non-completion from Tower 2 - Third Stage

Tower 2

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	2	0	0	0	0	0	0	2
2	Waiting for materials (supplier)	3	2	2	1	2	0	2	12
3	Waiting for tools and equipment	2	3	1	1	0	2	1	10
4	Lack of access	3	2	2	0	3	2	1	13
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	3	0	0	0	0	0	0	3
7	Changes/redoing work (site errors)	3	2	2	2	0	2	2	13
8	Moves to other work area	2	2	0	0	0	0	0	4
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	4	3	2	1	1	1	2	14
11	Overcrowded working areas	0	0	0	0	2	0	0	2
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Tower 2 "O activities"

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	1	0	0	0	0	0	0	1
2	Waiting for materials (supplier)	2	1	1	1	1	0	1	7
3	Waiting for tools and equipment	1	2	1	1	0	1	1	7
4	Lack of access	2	1	1	0	2	1	1	8
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	2	0	0	0	0	0	0	2
7	Changes/redoing work (site errors)	2	1	1	1	0	1	1	7
8	Moves to other work area	1	1	0	0	0	0	0	2
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	2	2	1	1	1	1	1	9
11	Overcrowded working areas	0	0	0	0	1	0	0	1
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Tower 2 "G activities"

No. ID	Reason for non-completion	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Total
1	Waiting for materials (on site)	1	0	0	0	0	0	0	1
2	Waiting for materials (supplier)	1	1	1	0	1	0	1	5
3	Waiting for tools and equipment	1	1	0	0	0	1	0	3
4	Lack of access	1	1	1	0	1	1	0	5
5	Equipment breakdowns	0	0	0	0	0	0	0	0
6	Changes/redoing work (design errors)	1	0	0	0	0	0	0	1
7	Changes/redoing work (site errors)	1	1	1	1	0	1	1	6
8	Moves to other work area	1	1	0	0	0	0	0	2
9	Waiting for information	0	0	0	0	0	0	0	0
10	Lack of continuity	2	1	1	0	0	0	1	5
11	Overcrowded working areas	0	0	0	0	1	0	0	1
12	Inclement weather	0	0	0	0	0	0	0	0
13	Other	0	0	0	0	0	0	0	0

Appendix C

Screening Activity Sheet (SAS) – Screening questions

APPENDIX C: SCREENING ACTIVITY SHEET (SAS) – SCREENING QUESTIONS

Change Order/Priority	Prerequisite work	Submittals	Design	Materials	Equipment	Labor	Space	Transportation
Was the activity re-scheduled?	Is the prerequisite work finished?	Are drawings available?	Are drawings clear?	Are ‘materials’ ready to be supplied?	Is the equipment available?	Are there enough workers available?	Are there ‘working conditions’ in the worksite?	Is horizontal transportation available?
Does the activity need to be re-scheduled?	Will the prerequisite work be finished on time?	Are materials specifications available?	Are design specifications clear?	Do ‘materials’ meet with the specifications?	Is the right equipment for the activity?	Do workers have the skills for executing the activity?	Is there ‘access’ to the worksite?	Is vertical transportation available?
		Are equipment specifications available?	Are there design changes?	Is it clear when and where ‘materials’ should be delivered?	Is the equipment ready?	Do workers know how to use the equipment?	Are there ‘working space conditions’ in the worksite?	
		Are technical specifications of construction process available?		Could ‘materials’ be delivered on time and in the place where they are needed?			Are there ‘working safety conditions’ in the worksite?	
		Are work permissions ready?						

Appendix D

Classification of Activities – ‘G and O activities’

APPENDIX D: CLASSIFICATION OF ACTIVITIES – "G AND O ACTIVITIES"

1	SITE ESTABLISHMENT & TEMPORARY WORKS			
	Activity	**G activity**	**O activity**	**Description of Relation - BEAM Section**
1.1	**Tower Cranes**			
1.1.1	Dismantle Tower Crane TC2 for Tower 1			Noise 2.3.2
1.1.2	Dismantle Tower Crane TC3 for Tower 2			Noise 2.3.2
1.2	**Material and Passenger Hoists**			
1.2.1	Dismantle Material Hoist MH1 for Tower 1			Noise 2.3.2 & Waste management systems 3.3.2a
1.2.2	Dismantle Material Hoist MH2 for Tower 2			Noise 2.3.2 & Waste management systems 3.3.2a
1.2.3	Dismantle Passenger Hoist PH1 for Tower 1			Noise 2.3.2 & Waste management systems 3.3.2a
1.2.4	Dismantle Passenger Hoist PH2 for Tower 2			Noise 2.3.2 & Waste management systems 3.3.2a

2	SUPERSTRUCTURE RC WORKS			
	Activity	**G activity**	**O activity**	**Description of Relation - BEAM Section**
2.1	**Tower 1**			
2.1.1	59/F - 60/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.2	60/F - 61/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.3	61/F - 62/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.4	62/F - 63/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.5	63/F - 65/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.6	65/F - 66/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.7	66/F - 67/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.8	67/F - 68/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.9	68/F - 69/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.10	69/F - R/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.11	Upper Roof at +217.3			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.12	Upper Roof at +220.7			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.13	Upper Roof at +224			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.1.14	Roof Parapet Wall			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2	**Tower 2**			
2.2.1	59/F - 60/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2

2.2.2	60/F - 61/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.3	61/F - 62/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.4	62/F - 63/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.5	63/F - 65/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.6	65/F - 66/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.7	66/F - 67/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.8	67/F - 68/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.9	68/F - 69/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.10	69/F - R/F			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.11	Upper Roof at +217.3			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.12	Upper Roof at +220.7			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.13	Upper Roof at +224			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.2.14	Roof Parapet Wall			Timber formwork 3.2.2a & precast 3.1.3 & 3.1.2
2.3	**Construction of Left Out Items**			
2.3.1	Construc L/O R.C. Tanks at G/F-L1			5.1.1a Fresh water plumbing
2.3.2	Construct L/O L1 Slab G.L. PB+ to PA+			
2.3.3	Construct L/O L1-L2 G.L. PB+ to PA+ (5.25 m H)			
2.3.4	L/O Rock Filling to L1-L2			
2.3.5	Construct L/O Parapet Wall at Open Carpark			

3 **BUILDING FAÇADE & ROOFING WORKS**

	Activity	G activity	O activity	Description of Relation - BEAM Section
3.1	**Podium**			
3.1.1	Ext Wall Rendering, Tiling and Sprayed Painting			2.3.1 Air Pollution & 3.1.5
3.1.2	Ext Louvre, Grille, Cladding, Glass Wall			6.6.1 Natural lighting + self cleaning glass & 3.2.4b Ozone depleting substances
3.1.3	Dismantle Ext. Scaffold			
3.1.4	L/O Ext Wall Finishes at Hoist Locations			
3.1.5	Dismantle Remaining Ext. Scaffold			
3.2	**Club House**			
3.2.1	Ext Cladding & Glass Wall			6.6.1 Natural light + self cleaning glass & 3.1.5
3.2.2	Dismantle Ext Scaffold			
3.2.3	L7 Outdoor Swimming Pool & Deck Finishes			5.2.5a pool + 6.8.2a amenity
3.2.4	L6 Roof Finishes & Landscaping Works			5.2.5a pool + 6.8.2a amenity & 2.2.4 & 2.2.5
3.2.5	Soft Landscaping Works			5.2.5a pool + 6.8.2a amenity & 2.2.4
3.3	**Towers 1 & 2**			

3.3.1	Window & Louvre Frame Installation		■	
3.3.2	Ext Wall Rendering & Tiling & Stone Cladding		■	
3.3.3	Ext Cladding, Fin & Remaining Glass Installation		■	
3.3.4	Ext A/C Unit Installation	■		4.3.1b
3.3.5	Ext Louvre Installation		■	
3.3.6	Dismantle Ext Scaffold (Low Zone)		■	
3.3.7	Dismantle Ext Scaffold (High Zone)		■	
3.3.8	Roof ext wall cladding / glass panel installation		■	
3.3.9	Roof W/P and Finishing Works		■	
3.3.10	BMU Installation & Testing	■		6.8.2b
3.3.11	Satellite Disc Installation	■		6.8.2a
3.3.12	L/O Ext Wall Finishes at Hoist Locations		■	
3.3.13	Dismantle Remaining Ext. Scaffold		■	

4 **MOCK-UPS & SAMPLE FLOORS**

	Activity	**G activity**	**O activity**	**Description of Relation - BEAM Section**
4.1	9/F Mock-Up Typical Flat/Lobby/Staircase/BOH		■	
4.2	35/F Mock-Up Flats A, B & C		■	

5 **ARCHITECTURAL FINISHING WORKS**

	Activity	**G activity**	**O activity**	**Description of Relation - BEAM Section**
5.1	**Basement & Podium**			
5.1.1	Ceiling Skim Coat/Plastering		■	
5.1.2	Wall Plastering	■		
5.1.3	Steel & Metal Works		■	
5.1.4	Ceiling & Wall Finishes & Fitting	■		3.2.4b Ozone depleting substances & 6.3.2 & 6.3.3
5.1.5	Entrance & Lift Lobbies Fitting Out Works		■	
5.1.6	Staircase & BOH Areas Finishes	■		3.2.4b Ozone depleting substances & 6.3.2 & 6.3.3
5.1.7	Carpark Floor Finishes, Marking & Fitting		■	
5.1.8	L1 Refuse Storage & MR Chamber Finishes		■	
5.1.9	L1 Turntable Installation		■	
5.1.10	L/O L1 & L2 Carpark Finishes at G.L. PB+ to PA+	■		3.2.4b Ozone depleting substances & 6.3.2 & 6.3.3
5.2	**Club House**			
5.2.1	Interior Fitting Out Works		■	
5.2.2	Final Decoration & Fitting		■	
5.3	**Towers 1 & 2**			
5.3.1	Door Frame Installation	■		3.2.2b

	Activity	G activity	O activity	Description of Relation - BEAM Section
5.3.2	Block Wall Erection	■		6.7.2
5.3.3	Metal Works Installation		■	
5.3.4	Ceiling Plastering	■		6.3.2 & 6.3.3
5.3.5	Wall Plastering	■		6.3.2 & 6.3.3
5.3.6	Waterproofing and Water Test	■		3.1.5
5.3.7	Lightweight Concrete, Floor Screeding		■	
5.3.8	Painting 1st coat	■		3.2.4b & 6.3.2 & 6.3.3
5.3.9	Stone & Marble Works		■	
5.3.10	Interior Fitting Out Works		■	
5.3.11	Kitchen Cabinet Installation		■	
5.3.12	Painting final coat	■		3.2.4b & 6.3.2 & 6.3.3
5.3.13	Kitchen Appliance Installation	■		4.3.6
5.3.14	Sanitary Fitting Installation	■		5.2.1, 5.2.1, 5.2.2
5.3.15	Signage Installation		■	
5.3.16	Timber Flooring	■		3.3.2b
5.3.17	Back of House Finishes		■	

6	**BUILDING SERVICES INSTALLATION**			
	Activity	**G activity**	**O activity**	**Description of Relation - BEAM Section**
6.1	**Basement & Podium**			
6.1.1	P&D 1st Fix	■		6.2.1
6.1.2	P&D 2nd Fix	■		6.2.1
6.1.3	P&D Final Fix	■		6.2.1
6.1.4	P&D Testing and Commissioning	■		4.4.1 & 6.2.1
6.1.5	FS 1st Fix	■		6.1.1a
6.1.6	FS 2nd Fix	■		6.1.1a
6.1.7	FS Final Fix	■		6.1.1a
6.1.8	FS Testing and Commissioning	■		4.4.1 + 6.1.1
6.1.9	Elect 1st Fix	■		4.2.6
6.1.10	Elect 2nd Fix	■		4.2.6
6.1.11	Elect Final Fix	■		4.2.6
6.1.12	Elect Testing and Commissioning	■		4.4.1 & 4.2.6
6.1.13	MVAC 1st Fix		■	
6.1.14	MVAC 2nd Fix		■	
6.1.15	MVAC Final Fix		■	

6.1.16	MVAC Testing and Commissioning			4.4.1 + 6.5.2b
6.2	**Club House**			
6.2.1	P&D 1st Fix			6.2.1
6.2.2	P&D 2nd Fix			6.2.1
6.2.3	P&D Final Fix			6.2.1
6.2.4	P&D Testing and Commissioning			4.4.1 & 6.2.1
6.2.5	FS 1st Fix			6.1.1a
6.2.6	FS 2nd Fix			6.1.1a
6.2.7	FS Final Fix			6.1.1a
6.2.8	FS Testing and Commissioning			4.4.1 + 6.1.1
6.2.9	Elect 1st Fix			4.2.6
6.2.10	Elect 2nd Fix			4.2.6
6.2.11	Elect Final Fix			4.2.6
6.2.12	Elect Testing and Commissioning			4.4.1 & 4.2.6
6.2.13	MVAC 1st Fix			
6.2.14	MVAC 2nd Fix			
6.2.15	MVAC Final Fix			
6.2.16	MVAC Testing and Commissioning			4.4.1 + 6.5.2b
6.3	**Towers 1 & 2**			
6.3.1	P&D 1st Fix			6.2.1
6.3.2	P&D 2nd Fix			6.2.1
6.3.3	P&D Final Fix			6.2.1
6.3.4	P&D Testing and Commissioning			4.4.1 & 6.2.1
6.3.5	FS 1st Fix			6.1.1a
6.3.6	FS 2nd Fix			6.1.1a
6.3.7	FS Final Fix			6.1.1a
6.3.8	FS Testing and Commissioning			4.4.1 + 6.1.1
6.3.9	Elect 1st Fix			4.2.6
6.3.10	Elect 2nd Fix			4.2.6
6.3.11	Elect Final Fix			4.2.6
6.3.12	Elect Testing and Commissioning			4.4.1 & 4.2.6
6.3.13	MVAC 1st Fix			
6.3.14	MVAC 2nd Fix			
6.3.15	MVAC Final Fix			

6.3.16	MVAC Testing and Commissioning	■		4.4.1 + 6.5.2b

7 PLANT ROOMS INSTALLATION

	Activity	G activity	O activity	Description of Relation - BEAM Section
7.1	**Podium**			
7.1.1	BW to G/F Water Meter Rm	■		4.4.3 & 5.2.2
7.1.2	G/F Water Meter Rm Installation		■	
7.1.3	BW to L2 Rain Water Pump Rm	■		5.2.2 & 5.2.5b + 6.2.1
7.1.4	L2 Rain Water Pump Rm Installation		■	
7.2	**Club House**			
7.2.1	BW to L6 Pool Filtration Plant Rm	■		2.3.5 & 6.2.1 & 5.2.4
7.2.2	L6 Pool Filtration System Installation		■	
7.3	**Towers 1 & 2**			
7.3.1	BW to 8/F-29/F EMR / WMR / ELV / Refuse Rm Install'n		■	
7.3.2	8/F-29/F EMR / WMR / ELV / Refuse Rm Install'n		■	
7.3.3	BW to 29R/F FS Pump & Tank Rm	■		5.1.1a + 6.2.1
7.3.4	29R/F FS Pump & Tank Rm Installation		■	
7.3.5	BW to 29R/F Fresh & Flushing Pump Rm	■		5.1.1a + 6.2.1
7.3.6	29R/F Fresh & Flushing Pump Rm Installation		■	
7.3.7	BW to 30/F-69/F EMR / WMR / ELV / Refuse Rms		■	
7.3.8	30/F-69/F EMR / WMR / ELV / Refuse Rm Intall'n		■	
7.3.9	BW to Lift Shafts & Pits (Low Zone)		■	
7.3.10	BW to Lift Shafts (High Zone)		■	
7.3.11	BW to Roof LMR		■	
7.3.12	Lift Installation (High Zone), Testing and Form 5	■		4.2.5
7.3.13	Lift Inspection by EMSD & Obtain Form 6	■		4.2.5
7.3.14	Handover Permanent Lifts for MC's Use	■		4.2.5
7.3.15	BW to Roof Fresh & Flushing Water Pump Rm	■		5.1.1, 5.3.1
7.3.16	Roof Fresh & Flushing Water Pump Room Install'n	■		5.1.1, 5.3.1
7.3.17	BW to Roof Genset Room		■	
7.3.18	Roof Genset Room Installation		■	

8 EXTERNAL WORKS

	Activity	G activity	O activity	Description of Relation - BEAM Section
8.1	Town Gas Lead-in Works		■	
8.2	WSD Water Pipe Lead-in Works		■	
8.3	External Drainage Connections	■		6.2.1

8.4	Construct L/O External G/F Slab / EVA			
8.5	G/F Loading/Unloading & EVA Finishes			
8.6	Dismantle Covered Walkway & Hoarding			2.2.7
8.7	Make Good Pavement & Metal Fence Wall / Gates			3.3.1

Appendix E

Pareto Charts – ‘G and O activities’

APPENDIX E: PARETO CHARTS – "G AND O ACTIVITIES"

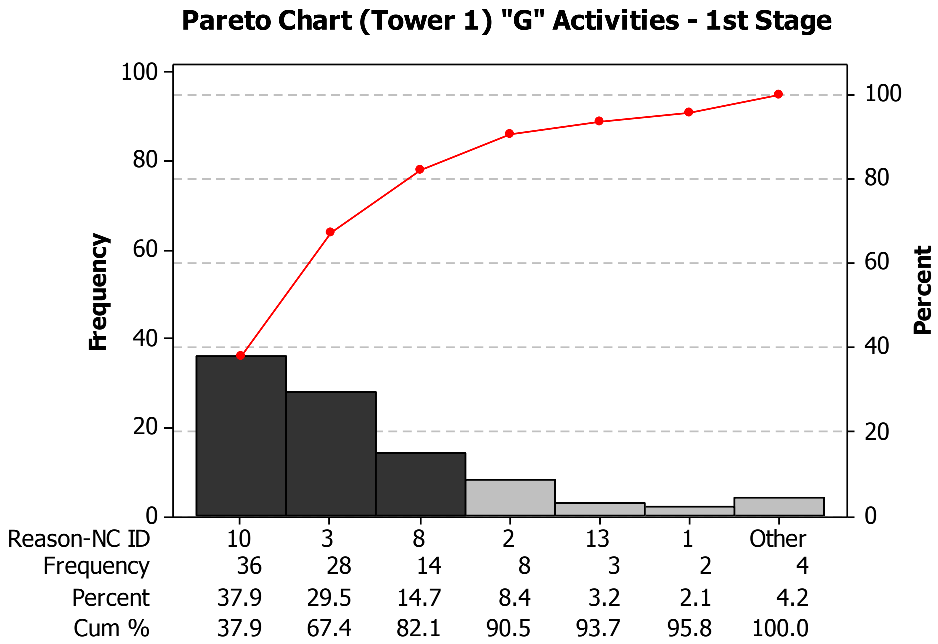


Figure 6.13 Pareto Chart of Reasons-NC 'G activities' (Tower 1) – 1st Stage

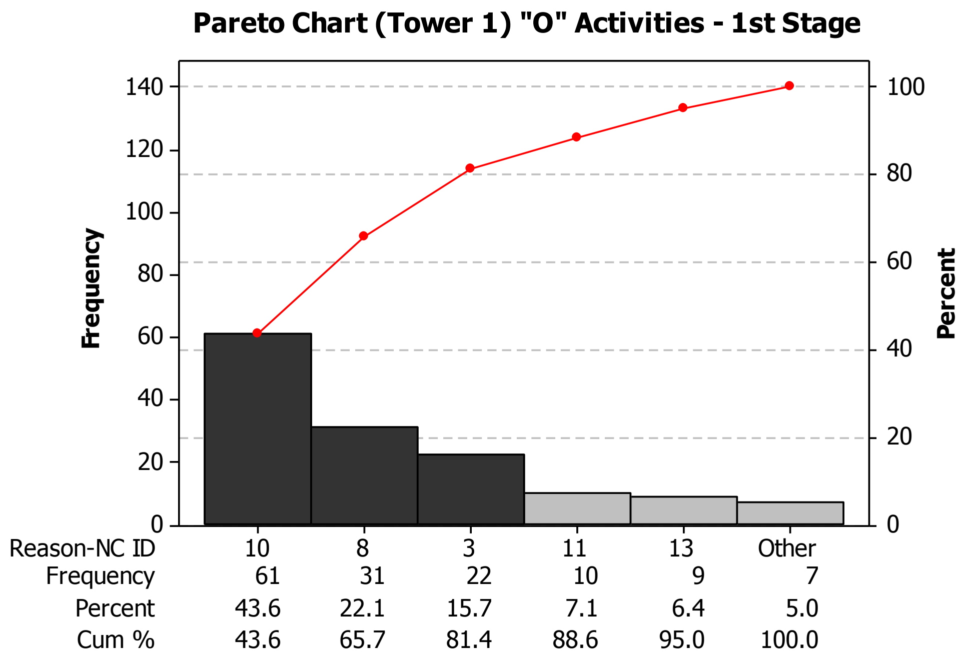
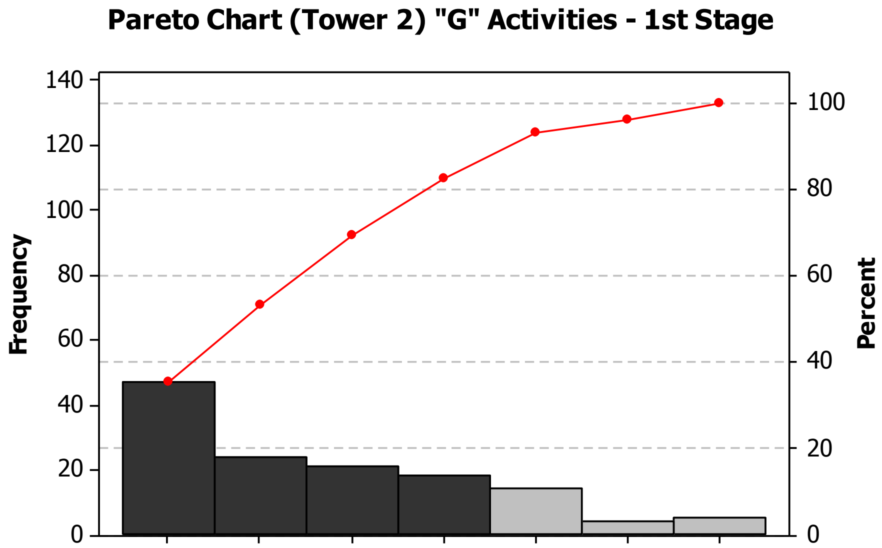
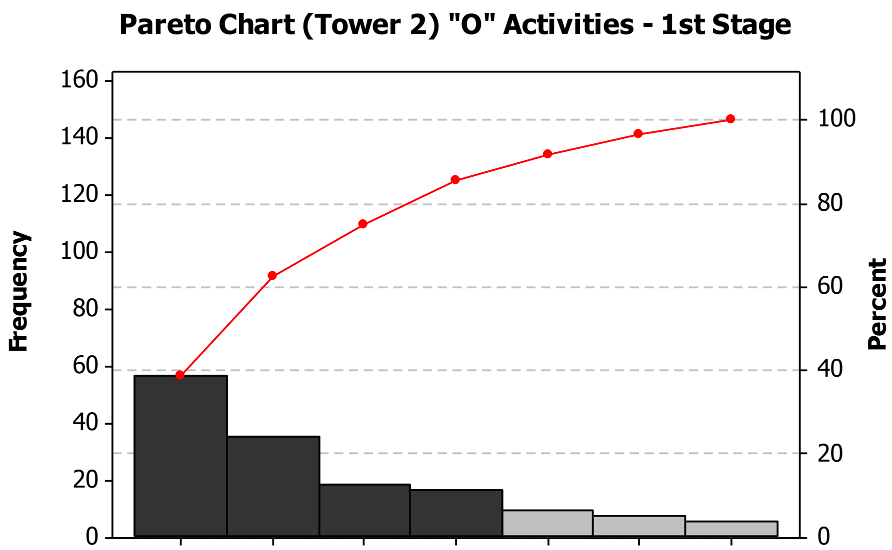


Figure 6.14 Pareto Chart of Reasons-NC 'O activities' (Tower 1) – 1st Stage



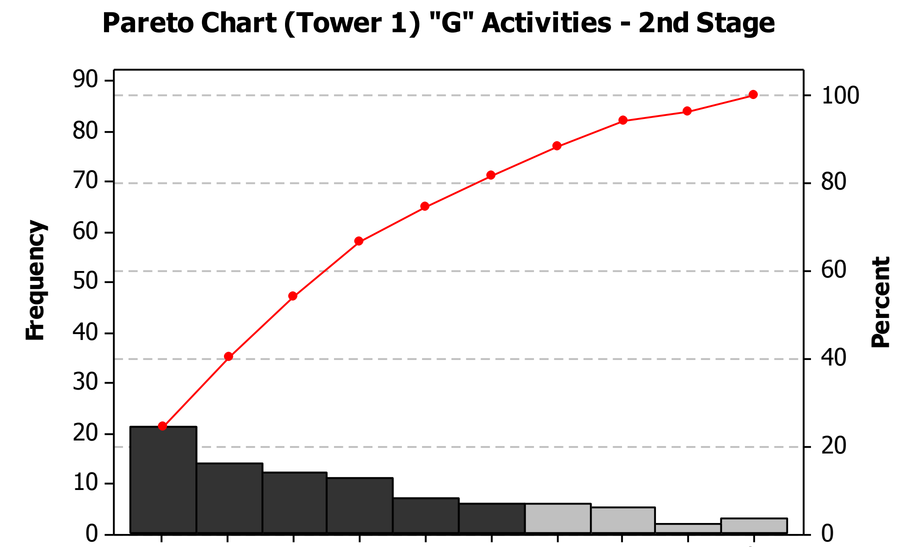
Reason-NC ID	10	8	3	2	13	11	Other
Frequency	47	24	21	18	14	4	5
Percent	35.3	18.0	15.8	13.5	10.5	3.0	3.8
Cum %	35.3	53.4	69.2	82.7	93.2	96.2	100.0

Figure 6.15 Pareto Chart of Reasons-NC ‘G activities’ (Tower 2) – 1st Stage



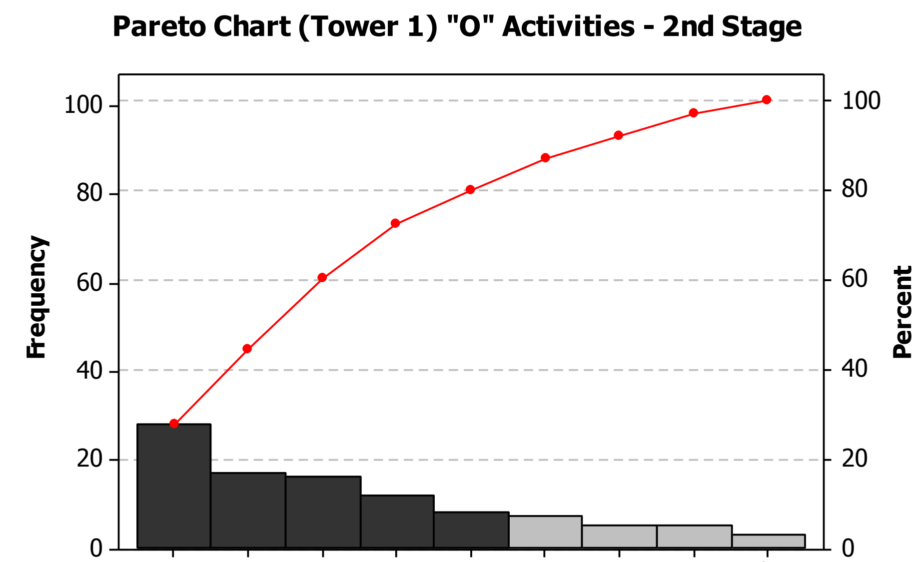
Reason-NC ID	10	8	13	3	2	11	Other
Frequency	56	35	18	16	9	7	5
Percent	38.4	24.0	12.3	11.0	6.2	4.8	3.4
Cum %	38.4	62.3	74.7	85.6	91.8	96.6	100.0

Figure 6.16 Pareto Chart of Reasons-NC ‘O activities’ (Tower 2) – 1st Stage



Reason-NC ID	10	8	3	2	7	1	11	4	6	Other
Frequency	21	14	12	11	7	6	6	5	2	3
Percent	24.1	16.1	13.8	12.6	8.0	6.9	6.9	5.7	2.3	3.4
Cum %	24.1	40.2	54.0	66.7	74.7	81.6	88.5	94.3	96.6	100.0

Figure 6.17 Pareto Chart of Reasons-NC 'G activities' (Tower 1) – 2nd Stage



Reason-NC ID	10	8	2	3	11	7	1	4	Other
Frequency	28	17	16	12	8	7	5	5	3
Percent	27.7	16.8	15.8	11.9	7.9	6.9	5.0	5.0	3.0
Cum %	27.7	44.6	60.4	72.3	80.2	87.1	92.1	97.0	100.0

Figure 6.18 Pareto Chart of Reasons-NC 'O activities' (Tower 1) – 2nd Stage

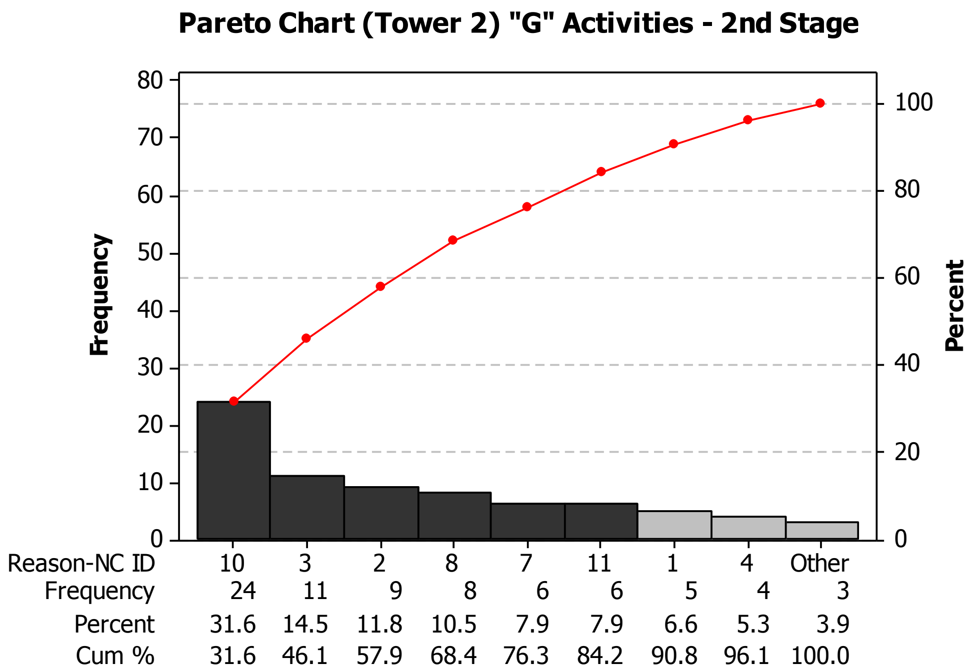


Figure 6.19 Pareto Chart of Reasons-NC ‘G activities’ (Tower 2) – 2nd Stage

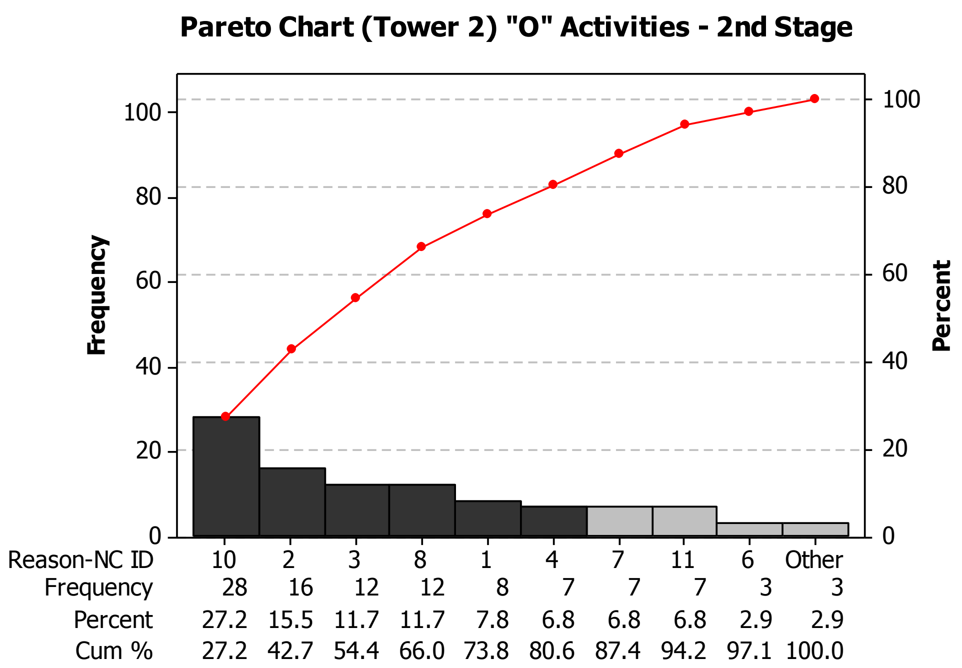
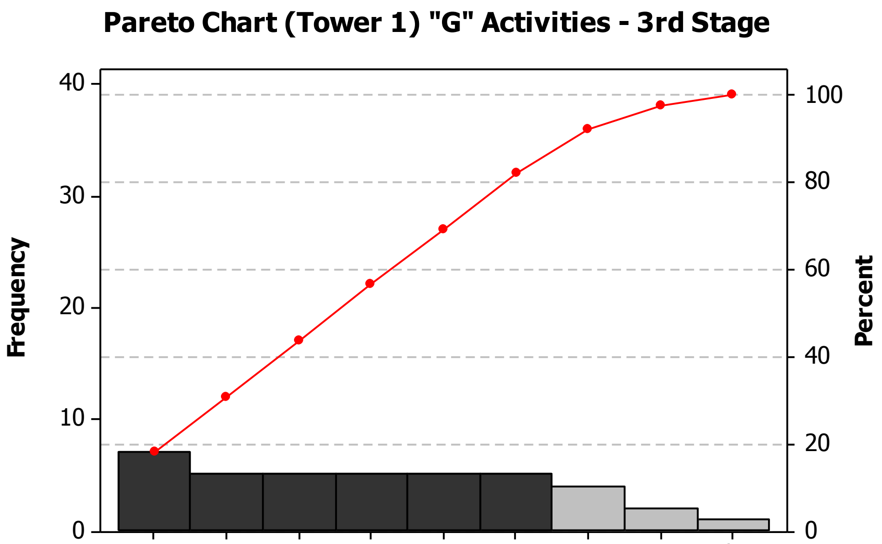
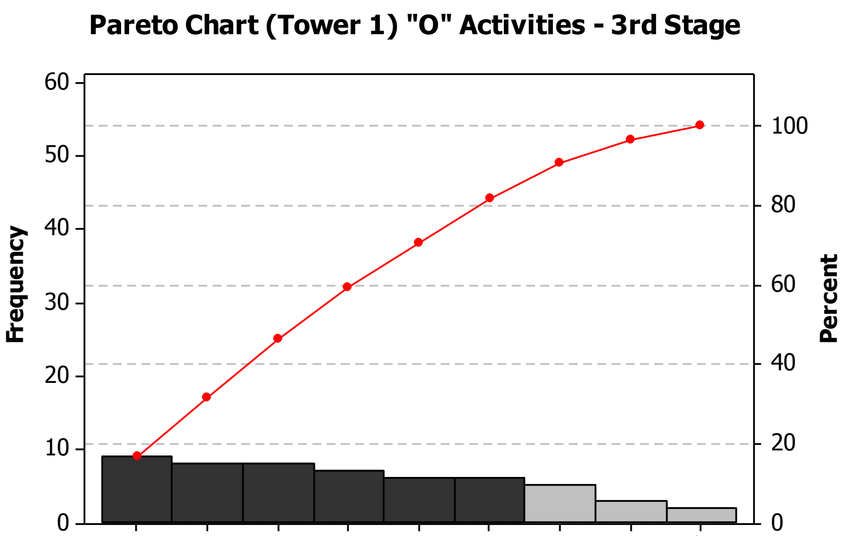


Figure 6.20 Pareto Chart of Reasons-NC ‘O activities’ (Tower 2) – 2nd Stage



Reason-NC ID	10	2	3	7	8	11	4	1	Other
Frequency	7	5	5	5	5	5	4	2	1
Percent	17.9	12.8	12.8	12.8	12.8	12.8	10.3	5.1	2.6
Cum %	17.9	30.8	43.6	56.4	69.2	82.1	92.3	97.4	100.0

Figure 6.21 Pareto Chart of Reasons-NC ‘G activities’ (Tower 1) – 3rd Stage



Reason-NC ID	7	2	10	3	4	11	8	1	Other
Frequency	9	8	8	7	6	6	5	3	2
Percent	16.7	14.8	14.8	13.0	11.1	11.1	9.3	5.6	3.7
Cum %	16.7	31.5	46.3	59.3	70.4	81.5	90.7	96.3	100.0

Figure 6.22 Pareto Chart of Reasons-NC ‘O activities’ (Tower 1) – 3rd Stage

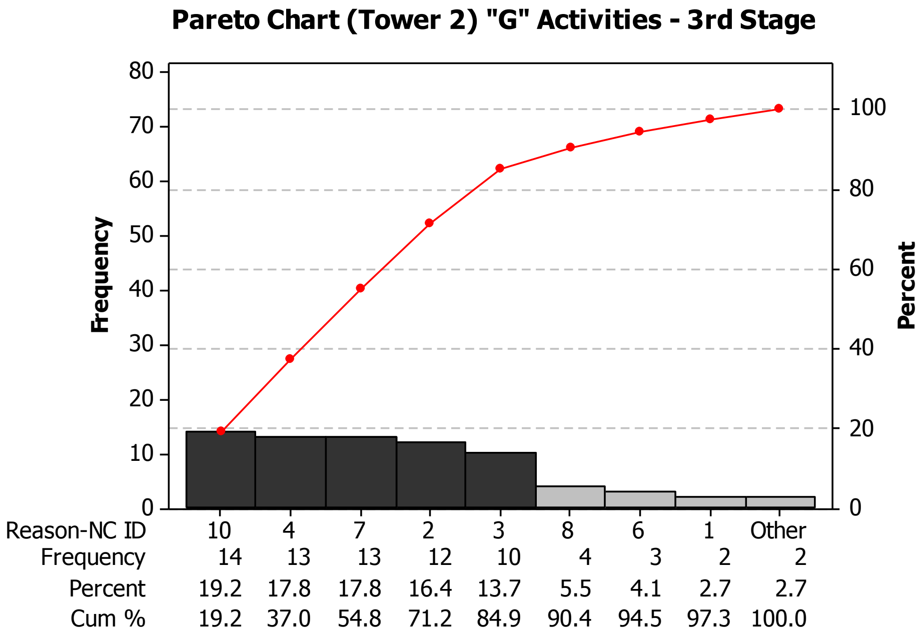


Figure 6.23 Pareto Chart of Reasons-NC ‘G activities’ (Tower 2) – 3rd Stage

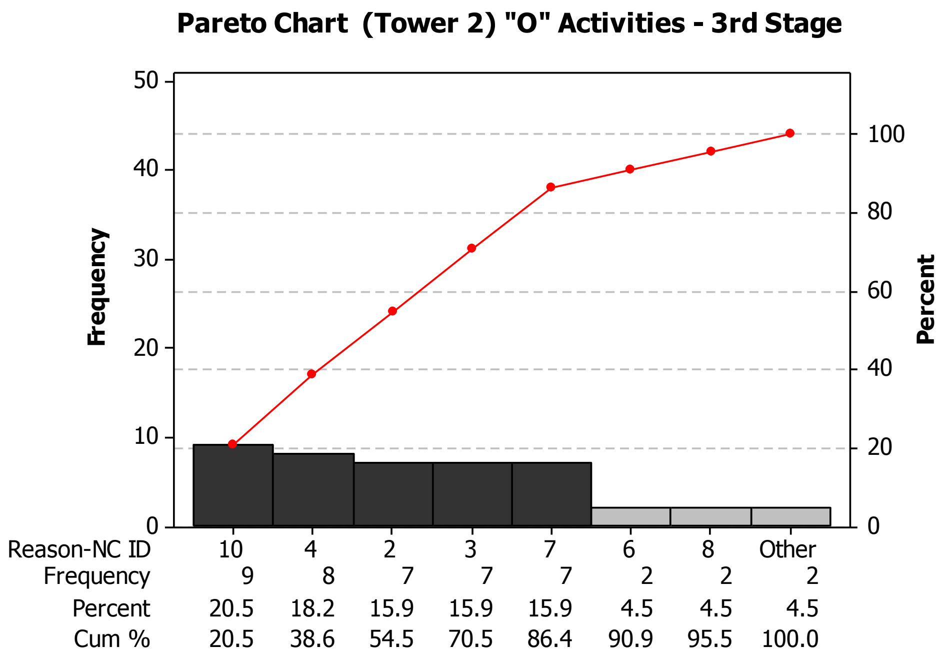


Figure 6.24 Pareto Chart of Reasons-NC ‘O activities’ (Tower 2) – 3rd Stage

Appendix F

P-Charts – ‘G and O activities’

APPENDIX F: P-CHARTS "G AND O ACTIVITIES"

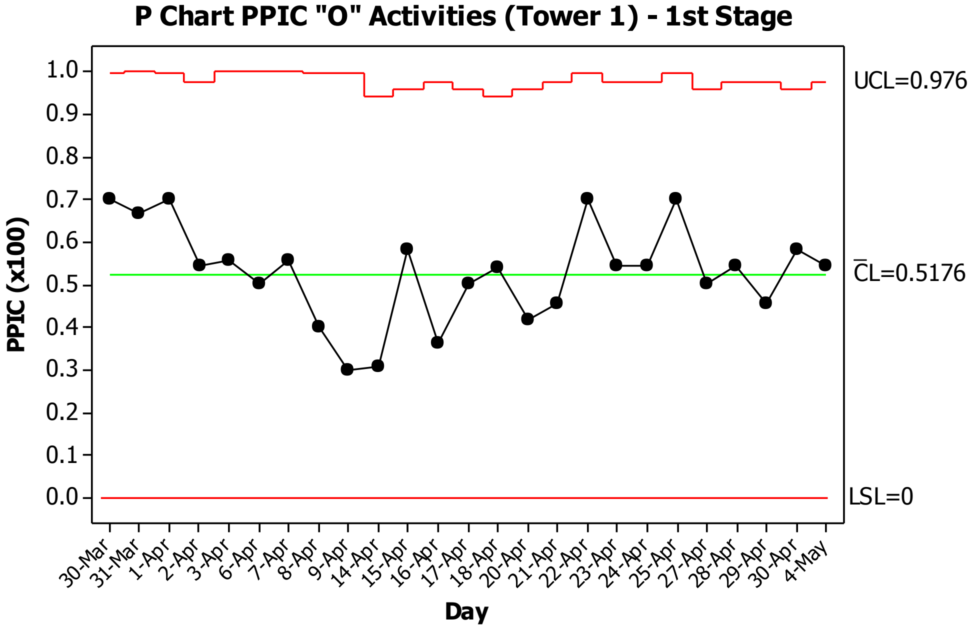


Figure 6.25 P-Chart PPIC 'O activities' (Tower 1) – 1st Stage

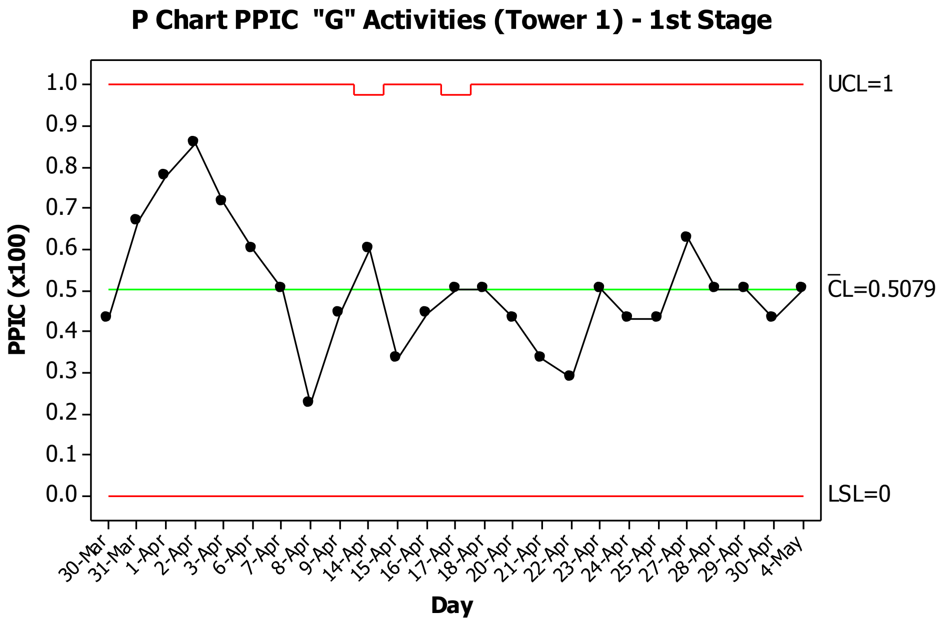


Figure 6.26 P-Chart PPIC 'G activities' (Tower 1) – 1st Stage

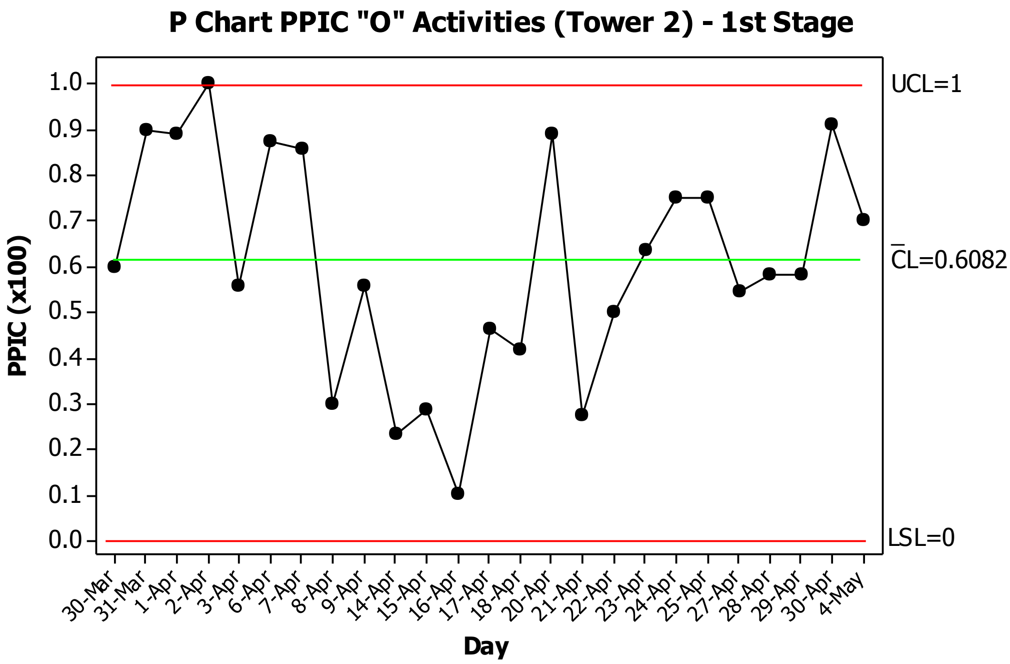


Figure 6.27 P-Chart PPIC 'O activities' (Tower 2) – 1st Stage

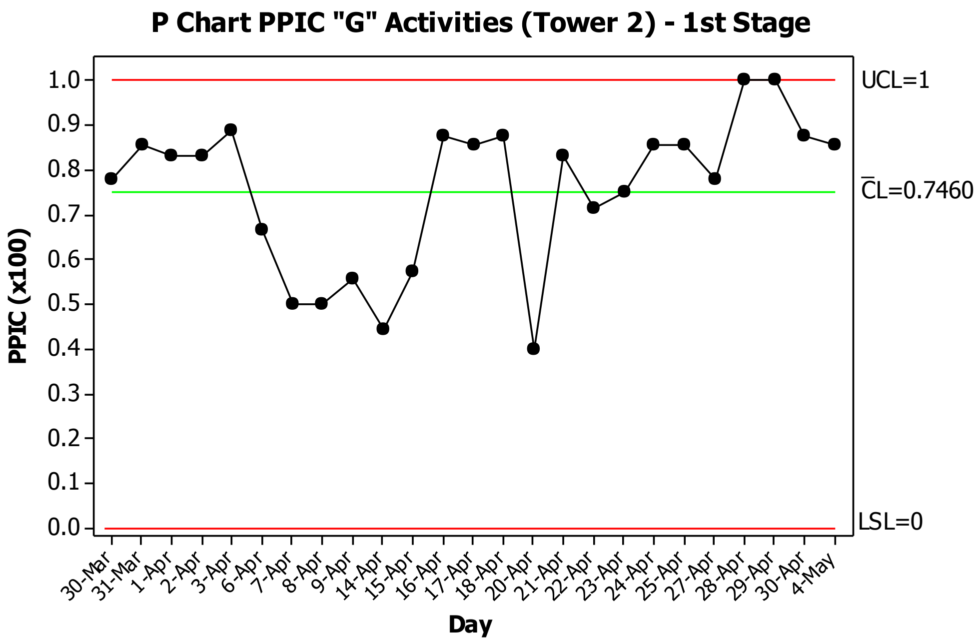


Figure 6.28 P-Chart PPIC 'G activities' (Tower 2) – 1st Stage

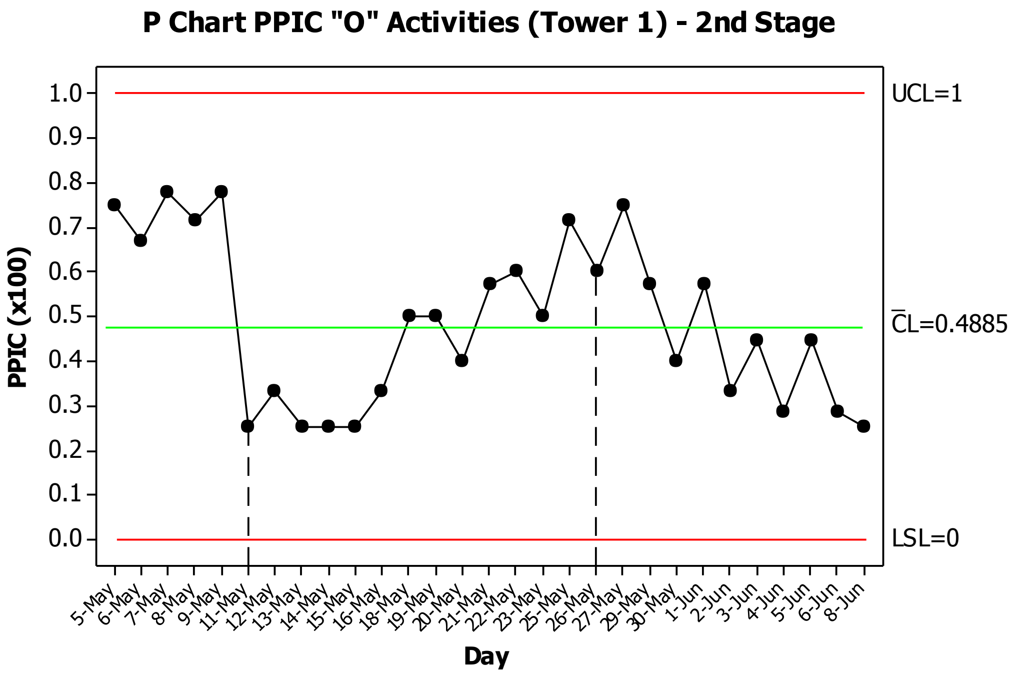


Figure 6.29 P-Chart PPIC 'O activities' (Tower 1) – 2nd Stage

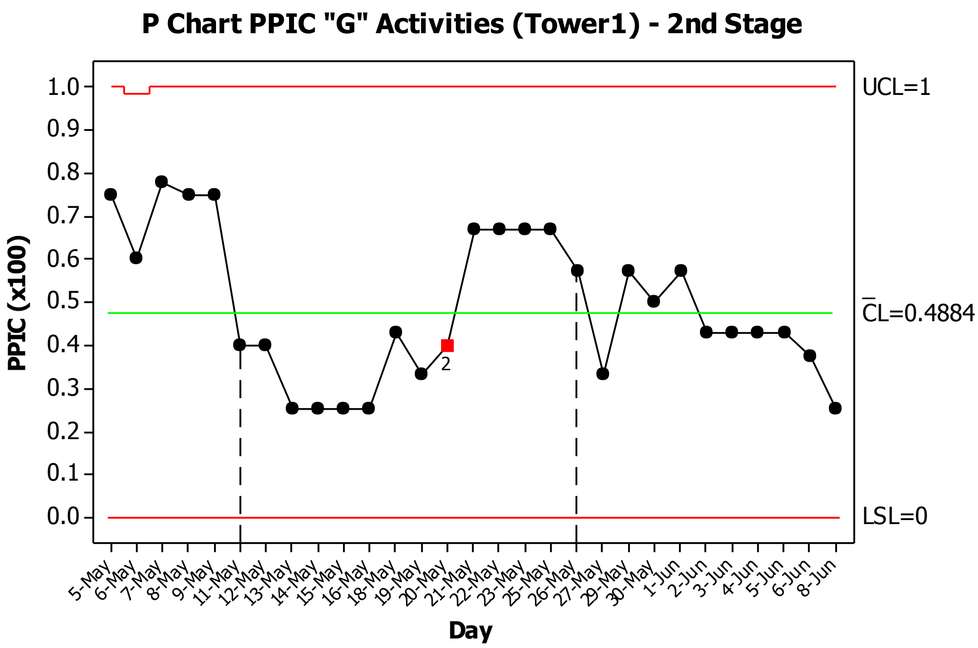


Figure 6.30 P-Chart PPIC 'G activities' (Tower 1) – 2nd Stage

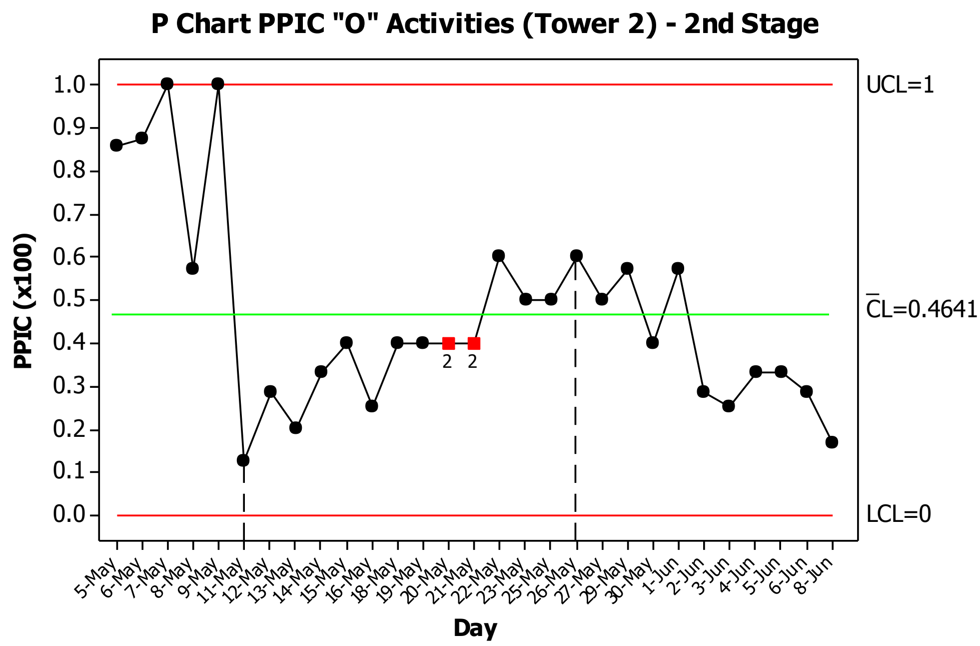


Figure 6.31 P-Chart PPIC ‘O activities’ (Tower 2) – 2nd Stage

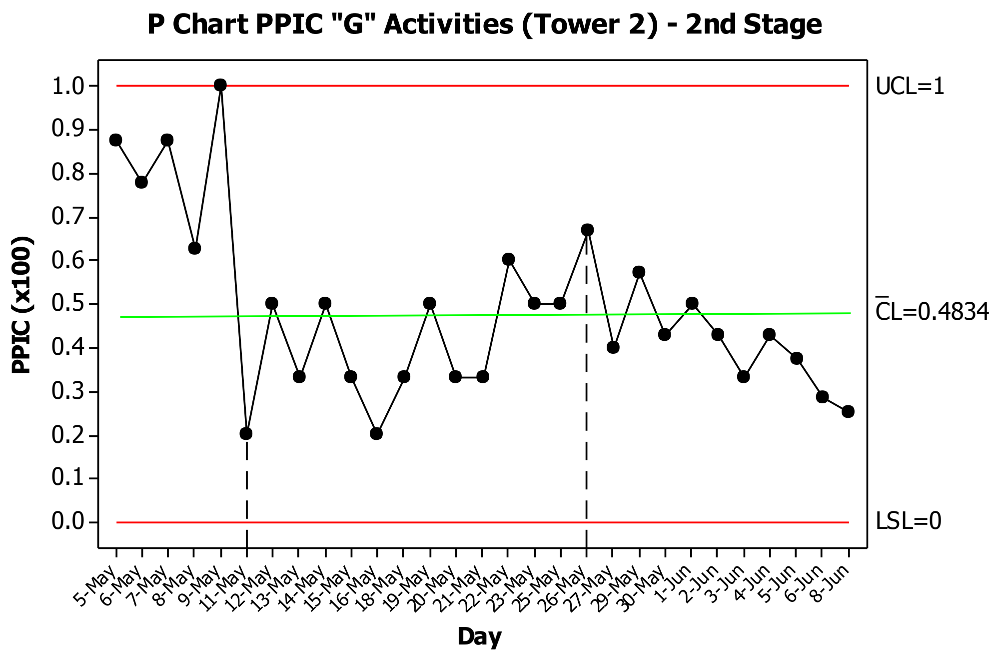


Figure 6.32 P-Chart PPIC ‘G activities’ (Tower 2) – 2nd Stage

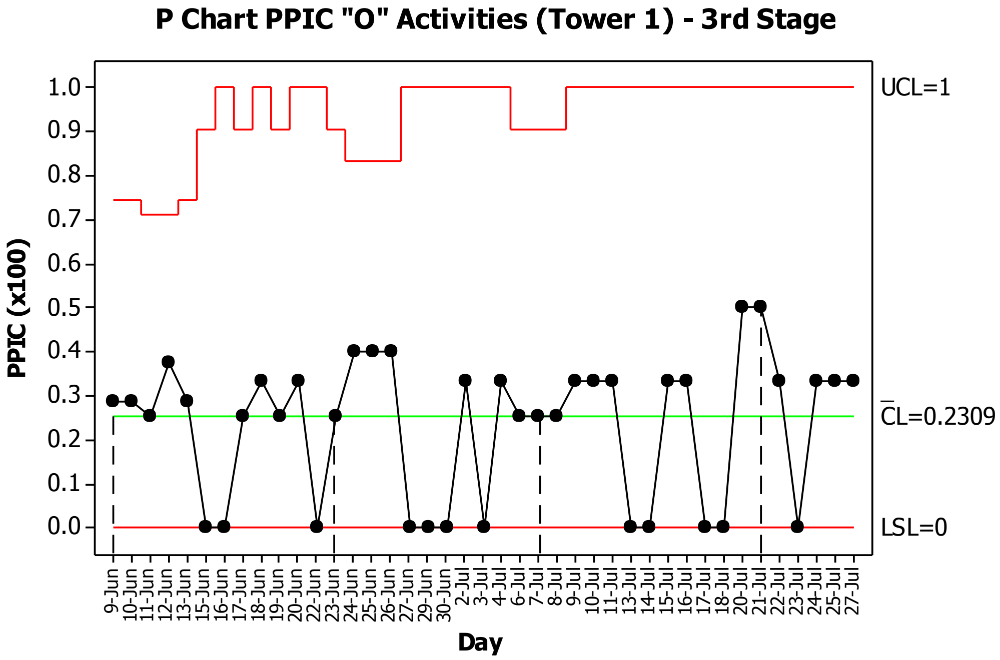


Figure 6.33 P-Chart PPIC ‘O activities’ (Tower 1) – 3rd Stage

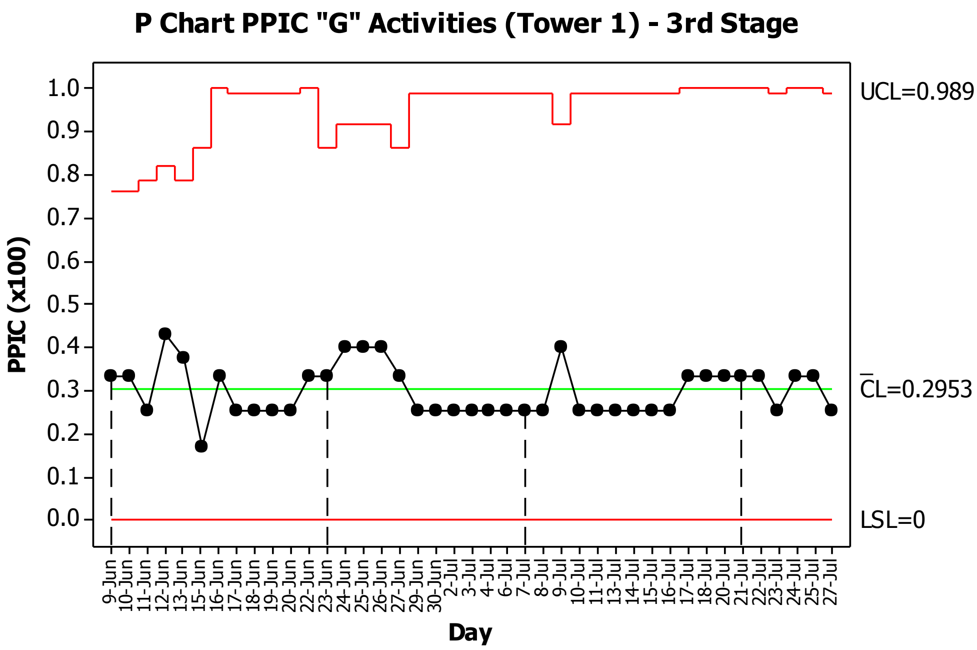


Figure 6.34 P-Chart PPIC ‘G activities’ (Tower 1) – 3rd Stage

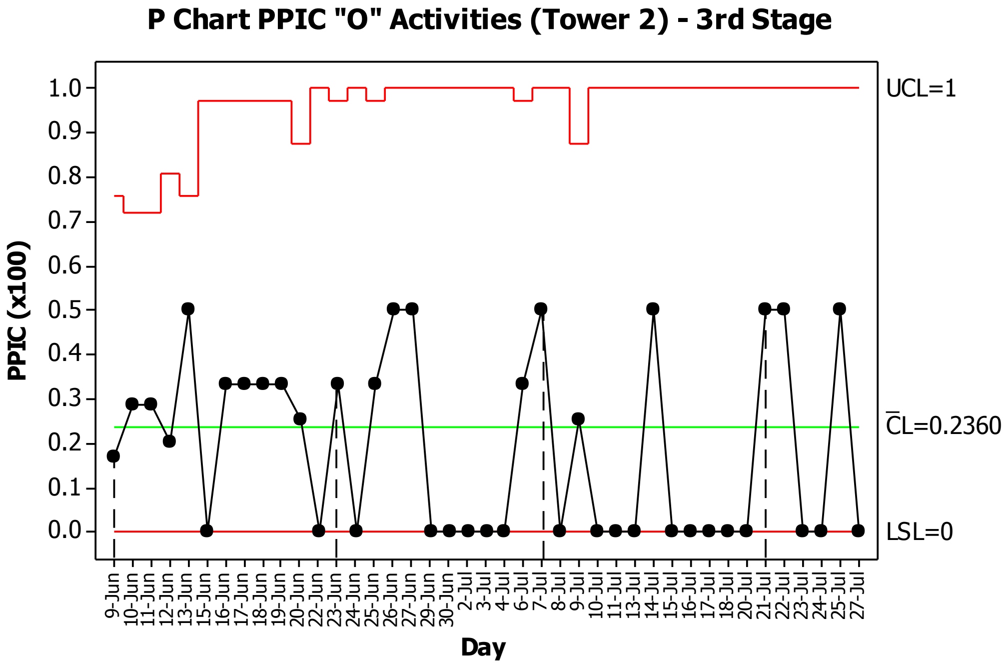


Figure 6.35 P-Chart PPIC 'O activities' (Tower 2) – 3rd Stage

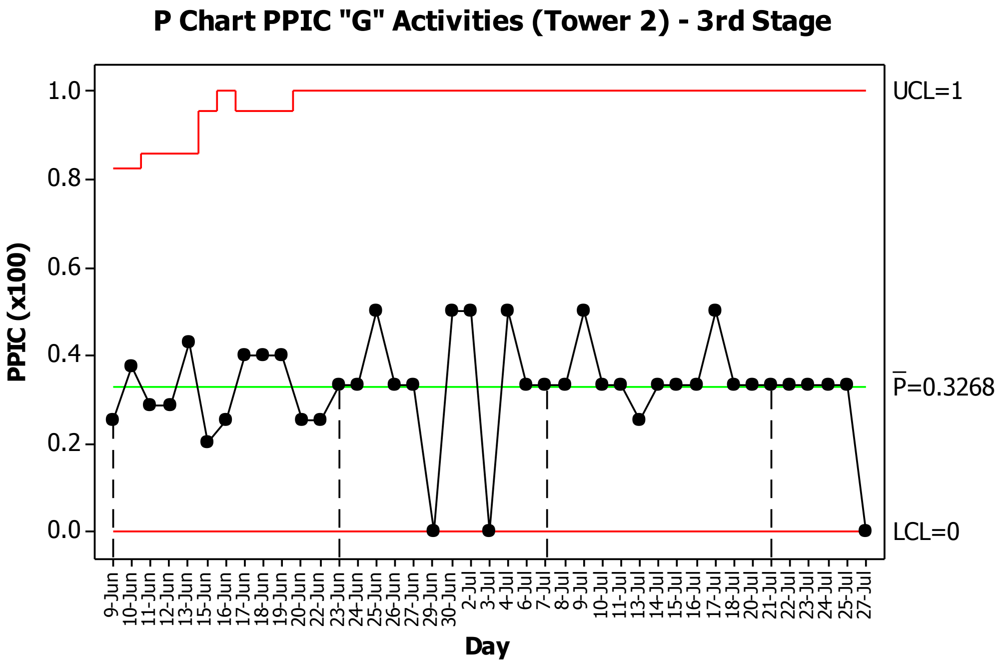


Figure 6.36 P-Chart PPIC 'G activities' (Tower 2) – 3rd Stage

Appendix G

Evaluation Questionnaire

APPENDIX G: EVALUATION QUESTIONNAIRE

Evaluation Questionnaire

The evaluation questionnaire is designed to gather your opinion on the performance of the proposed planning system implemented in the “XXXXX“ project. The information collected will help to detect the areas in the system that need to be improved. Your opinion is important for the further development of the system.

Instructions

Unless otherwise stated, please indicate your answers by circling the appropriate numbers. The meaning of the acronyms are given under the table

1. Basic Information:

Your role in the project:

θ Consultant θ Contractor θ Subcontractor θ Supplier

2. To what extent do you agree with the following statements about the system?

	SA	A	N	D	SD
1. The availability of data was improved…………………….	5	4	3	2	1
2.The decision-making in the planning process was improved?...	5	4	3	2	1
3. The method produced benefits…………………………….	5	4	3	2	1
4. A number of key gaps in my organization’s ability to have more reliable plans were identified……………………………	5	4	3	2	1
5.The method helped me clarify my understanding of interagency roles and responsibilities of parties during the production planning process………………………………….	5	4	3	2	1
6. The method allowed me to have a greater awareness of the problems, needs, and concerns of other project parties……………………………………...............................	5	4	3	2	1
7. It was laborious to work according to the method……….	5	4	3	2	1
5. The method should be used in the next project………….	5	4	3	2	1

(SA: Strongly Agree, A: Agree, N: Neutral, D: Disagree, SD: Strongly Agree)

Thank you very much for completing this questionnaire!

-The End-

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