Develop a Lean project management framework for the construction companies in order to improve the time and cost efficiencies of their construction operations

By

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Abstract

This research explores how Lean management principles, tools and techniques could be used in conjunction with project management theories to develop a Lean project management framework for the Saudi construction firms in order to improve the time and cost efficiencies

of their operations. It critically evaluates the applicability of Lean's philosophy in the construction industry. It also investigates the management implication of traditional project management practices and the performance-improvement potential of pro-Lean practices. It examines how the adoption of Lean's Kanban can help firms to address the problem of time and cost overruns. It uses Simio 10 computer simulation software to simulate the impact of Kanban's adoption on the time and cost efficiencies of construction activities using 54 real-life scenarios. It identifies the key drivers, enablers and barriers to the adoption of Kanban in the Saudi construction industry using semi-structured interviews and web-based survey questionnaires.

This research has found that construction firms in Saudi Arabia are struggling with the management of delays and that their activities are characterised by cost and schedule overruns. Saudi Arabia has, for many years, invested billions of pounds in infrastructure projects, particularly on transport initiatives such as new roads, ports and bridges. However, not many of these initiatives have been completed in time or on budget. In fact, delays and cost overruns are so common in the country that they have become seen as the norm and as a reality that project managers should just accept.

This research has also found that the principles of 'Lean Construction' and Kanban's 6 rules in particular offer a viable solution to many of the current problems of Saudi construction firms. Kanban enables construction companies to switch from push-based systems to pull-based systems which involve real-time monitoring of consumption and demand-triggered replenishment. Kanban's adoption also ensures that the capacities of upstream and downstream processes are perfectly aligned, which helps firms to reduce bottlenecks, avoid backlogs and fine-tune their processes and construction activities.

Moreover, this research has found that Lean construction's success depends heavily on senior management's commitment and also on staff training and understanding of the technical requirements of Lean's systems. In fact, lack of commitment and senior managers' short-sighted investment policies are identified as the two most significant barriers to Lean construction's principles' adoption and operationalisation.

Declaration

This work or any part thereof has not been previously presented in any form to the University or to any other body for the purpose of assessment, publication or any other purpose. Unless indicated for any express acknowledgement, reference and or/ bibliographies cited in the work, I confirm that the intellectual content of the work is the result of my own efforts and of no other person and therefore, I, Mohammed Alhalafi should be identified as the author of this work at all time.

Signature…………………………………… Date………………………………….

Research Publications

- *A Critical Review of Lean Project Management and Its Application in Construction Project Management.* A Peer Reviewed Paper Published in the International Journal of Scientific and Engineering Research (IJSER) 2017.

- *Passenger Departure Process Modelling to Investigate the Effect of Variability for Major International Airport.* A Paper Presented at the Administrative Science Association of Canada (ASAC) Conference, Ryerson University, Toronto, Canada, May 2018.

- *Application of Lean Project Management in Construction: A Review of Performance Improvement*. A paper presented at the 30th European Conference on Operational Research (EURO 2019) June 23-26, 2019 in Dublin, Ireland.

List of Contents

Acknowledgements II

Abstract II

Declaration III

Research Publications IV

Chapter One: Introduction 1

  1.1 Research Background 1

  1.2 Research Problem 4

  1.3 Research Motivation 6

1.4 Research Questions 7
1.5 Research Aim and Objectives 8
1.6 Scope of Research 8
1.7 Contributions to Knowledge 10
1.8 Research Novelty 11
1.9 Overview of Research Methodology 12
1.10 Thesis Structure 13
Chapter 2: Literature Review - Project Management 15
2.1 Introduction 15
2.2 The Nature of the Construction Industry 16
2.2.1 Characteristics of the Construction Industry 18
2.2.2 Overview of the Saudi Construction Industry 20
2.3 Performance of the Saudi Construction Industry 23
2.4 Delay in Construction Projects 25
2.4.1 Causes of Delay in Construction Projects 26
2.4.2 Types of Delays 30
2.4.3 Impact of Delays 33
2.4.4 Construction Project Delays in Different Countries 34
2.5 Project Management 37
2.6 Importance of Project Management 38
2.7 Construction and Project Management 38
2.7.1 Definition of Project Management in Construction 40
2.7.2 Characteristics of Project Management in the Construction Sector 40
2.7.2.1 Scheduling in Construction Project 41
2.7.2.2 Tools and Techniques in Construction Project Management 42
2.8 Issues in the Construction Project Management 44
2.8.1 Project Management Theory is based on the Management-as-Planning 45
2.8.2 Project Management Theory is based on Transformation 46
2.9 Summary 48
Chapter 3: Literature Review - Lean Construction 49
3.1 Introduction 49
3.2 Concept of Lean in Construction 50
3.3 Lean Construction Principles 52
3.4 Lean Waste in Construction Projects 53
3.5 Lean Construction Tools and Techniques 55
3.6 Lean's Impact on Planning and Control Activities 57
3.7 Challenges in the Implementation of Lean in Construction Project Management 58

3.8 Benefits of Lean Construction Project Management ... 60
3.9 Review of Existing Lean Construction Frameworks ... 62
3.9.1 Lean - A Framework ... 62
3.9.2 Lean Enterprise Architecture ... 63
3.9.3 Lean Assessment Tool ... 64
3.9.4 The Lean Project Delivery System ... 64
3.9.5 The 4P Model of Lean ... 66
3.9.6 Cost-Time-Profile ... 67
3.9.7 Framework for Describing the Levels of Lean Capability ... 67
3.9.8 Impact Assessment Framework ... 67
3.10 Lean and Project Management Synergies ... 68
3.11 Summary ... 72
Chapter 4: Research Methodology ... 73
4.1 Introduction ... 73
4.2 Research Scope ... 73
4.3 Development of Research Methodology ... 74
4.4 Research Philosophy ... 74
4.5 Research Approach ... 78
4.6 Methodical Choices ... 80
4.7 Research Strategy ... 86
4.7 Time Horizon ... 89
4.8 Data Collection ... 89
4.8.1 Sampling Approach ... 92
4.8.2 Simulation and Modelling ... 93
4.9 Design of Experiments ... 94
4.10 Modelling of Kanban's Impact Using DES ... 96
4.11 Validation of Research Propositions ... 99
4.11.1 Validation - 1st Stage ... 99
4.11.2 Validation - 2nd Stage ... 101
4.12 Ethical Consideration ... 103
4.13 Chapter Summary ... 103
Chapter 5: Data Analysis & Interpretation ... 104
5.1 Introduction ... 104
5.2 Findings from Interviews ... 104
5.2.1 Theme A: Operational Challenges and Lean Construction ... 108
5.2.2 Theme B: Efficacy of Traditional Project Management ... 108
5.2.3 Theme C: Project Planning and Control Methods ... 110

5.2.4 Theme D: Perception of Lean Construction 112
5.2.5 Theme E: Drivers and Benefits of Lean Construction 114
5.2.6 Theme F: Enablers and Facilitators of Lean Construction 117
5.2.7 Theme G: Barriers and Challenges of Lean Construction 122
5.3 Findings from Questionnaire 126
5.3.1 Part 1: Descriptive Statistics 127
5.3.2 Part 2: Awareness and Knowledge of Management Practices 129
5.3.3 Part 3: Perceived Benefits of Lean Construction 129
5.3.4 Part 4: Experienced Impact of Lean Construction 133
5.3.5 Part 5: Barriers and Enablers of Lean Construction 135
5.3.6 Part 5: Lean Project Management and Performance 138
5.4 Quantitative Data Validation 139
5.5 Process Map Development 140
5.6 Taguchi Data - Design of Experiments 144
5.6.1 Deployment of the Taguchi Technique 145
5.7 Project Process Mapping – Linking Data to Simulation Model 150
5.8 Summary 151
Chapter 6: Assessment of Current State 153
6.1 Introduction 153
6.2 Differences and Similarities between Manufacturing and Construction 153
6.3 Simulation Model: Discrete Processes 154
6.4 Simulation Procedure 155
6.4.1 Analysis of Framing Actual Time 157
6.4.2 Analysis of Framing Actual Cost 158
6.4.3 Analysis of Windows Actual Time 159
6.4.4 Analysis of Windows Actual Cost 160
6.4.5 Analysis of Elevators Actual Time 161
6.4.6 Analysis of Elevators Actual Cost 162
6.4.7 Analysis of Electrical Actual Time 163
6.4.8 Analysis of Electrical Actual Cost 164
6.4.9 Analysis of Drywall Actual Time 165
6.4.10 Analysis of Drywall Actual Cost 166
6.4.11 Analysis of Exterior Casework Actual Time 167
6.4.12 Analysis of Exterior Casework Actual Cost 168
6.5 Summary 169
Chapter 7: Kanban-Facilitated Improvements 172
7.1 Introduction 172

7.2 Kanban's Improvement Potential 172
7.3 Improvement Strategy 174
7.3.1 Applying 6-Rules of Kanban to Framing 175
7.3.2 Applying 6-Rules of Kanban to Windows 177
7.3.3 Applying 6-Rules of Kanban to Electrical 179
7.3.4 Applying 6-Rules of Kanban to Elevators 182
7.3.5 Applying 6-Rules of Kanban to Drywall 185
7.3.6 Applying 6-Rules of Kanban to Exterior Casework 187
7.4 Impact of Kanban's 6 Rules on Supply Delay 189
7.5 Summary 198
Chapter 8: Discussion 200
8.1 Introduction 200
8.2 Transfer of Lean Manufacturing's Principles for Construction 200
8.3 Lean Project Management 202
8.5 Enablers, Drivers and Barriers to Kanban's Adoption 205
8.6 Novelty of Research 208
8.7 Contributions to Knowledge 213
8.8 Research Limitations 214
8.9 Summary 215
Chapter 9: Conclusions 216
9.1 Introduction 216
9.2 Conclusions 217
9.2.1 Objective 1: Operational Problems of Saudi Construction Firms 217
9.2.2 Objective 2: Efficacy of Traditional Project Management 217
9.2.3 Objective 3: Obstacles to Optimal Operational Performance 218
9.2.4 Objective 4: Lean Project Management 219
9.2.5 Objective 5: Improvements 220
9.3 Future Research 220
10. References 222
11. Appendices 257
11.1 Appendix I: Research Questions 257
11.2 Appendix II: Questionnaire 258
11.3 Appendix III: Interview Questions 263
11.4 Appendix IV: Sample Interview Transcript 264
11.5 Appendix V (Correspondences with BCC) 270
11.6 Appendix VI: SIMIO Simulation Screenshots 272
11.7 Appendix VII: SIMIO Simulation Tables – Scenarios 279

List of Figures

Figure 2: 1 Dynamism of a Typical Construction Project in Jeddah, Saudi Arabia........................ 17
Figure 2: 2 Economic Contributions of Construction Industry in Different Countries.................... 19
Figure 2: 3 Map of Saudi Arabia.. 21
Figure 2: 4 Locations of the Saudi Economic Cities.. 22
Figure 2: 5 - managerial process in project management.. 45

Figure 3: 1 - Framework for Implementing Lean Techniques 61
Figure 3: 2 - Lean - A Framework 62
Figure 3: 3 - Lean Enterprise Architecture Phases... 63
Figure 3: 4 - Lean Assessment Tool: Spider-web Diagram 64
Figure 3: 5 - LPDS System 65
Figure 3: 6 - Application of Lean's Principles in Project Management 71

Figure 4: 1 - The research 'Onion'.. 74
Figure 4: 2 - Deductive approach.. 78
Figure 4: 3 - Inductive approach 79
Figure 4: 4 - Population, samples and Individual cases 92
Figure 4: 5 - Flow Chart of Taguchi Method Steps 95

Figure 5: 1 - Process Map of Construction Activities 141
Figure 5: 2 - Map of Critical Paths of Construction Activities 142
Figure 5: 3 - Current State of Simulation Model Flow Chart... 150

Figure 6: 1 - Main Effects Plot for Framing Actual Time (Day) 158
Figure 6: 2 - Main Effects Plot for Framing Actual Cost (SAR) 159
Figure 6: 3 - Main Effects Plot for Windows Actual Time (Day).. 160
Figure 6: 4 - Main Effects Plot for Windows Actual Cost (SAR).. 161
Figure 6: 5 - Main Effects Plot for Elevators Actual Time (Day).. 162
Figure 6: 6 - Main Effects Plot for Elevators Actual Cost (SAR).. 163
Figure 6: 7 - Main Effects Plot for Electrical Actual Time (Day).. 164
Figure 6: 8 - Main Effects Plot for Electrical Actual Cost (SAR).. 165
Figure 6: 9 - Main Effects Plot for Drywall Actual Time (Day).. 166
Figure 6: 10 - Main Effects Plot for Drywall Actual Cost (SAR).. 167
Figure 6: 11 - Main Effects Plot for Exterior Casework Actual Time (Day)................................ 168
Figure 6: 12 - Main Effects Plot for Exterior Casework Actual Cost (SAR)................................ 169

Figure 7: 1 - Steps of Improvement 174
Figure 7: 2 Simio Process Map 272
Figure 7: 3 Pre-Kanban Simio Process Outputs.. 273
Figure 7: 4 Pre-Kanban Cost and Lead Time for Framing Activity... 274
Figure 7: 5 Pre-Kanban Delay Estimates for Framing Activity 275
Figure 7: 6 Post-Kanban Adoption Simio Process Outputs 276
Figure 7: 7 Post-Kanban Adoption Cost and Lead Time for Framing Activity............................ 277
Figure 7: 8 Post-Kanban Adoption Delay Estimates for Framing Activity 278
Figure 7: 9 Framing Lead Time for Before and After Kanban's Adoption.................................. 191
Figure 7: 10 - Kanban's Impact on Supply Delay in Framing Activity... 191

Figure 7: 11 Windows Lead Time for Before and After Kanban's Adoption 194
Figure 7: 12 - Kanban's Impact on Supply Delay in Windows Activity 194
Figure 7: 13 Electrical Lead Time for Before and After Kanban's Adoption 195
Figure 7: 14 - Kanban's Impact on Supply Delay in Electrical Activity 195
Figure 7: 15 Elevators Lead Time for Before and After Kanban's Adoption 196
Figure 7: 16 - Kanban's Impact on Supply Delay in Elevators Activity 196
Figure 7: 17 Drywall Lead Time for Before and After Kanban's Adoption 197
Figure 7: 18 - Kanban's Impact on Supply Delay in Drywall Activity 197
Figure 7: 19 Exterior Casework Lead Time for Before and After Kanban's Adoption 198
Figure 7: 20 - Kanban's Impact on Supply Delay in Exterior Casework Activity 198

List of Tables

Table 2: 1 - Delays to Construction Projects: Their Causes and Effects... 26
Table 2: 2 - Delays as Ranked by Contractors 27
Table 2: 3 - Delay Causes According to Consultants... 27
Table 2: 4 - Views on Construction Delay across Selected Nations 36
Table 2: 5 - Definition of Project Management 37
Table 2: 6 - Ingredient of a new theoretical foundation of project management 47

Table 3: 1 - Definitions of Lean Construction 51
Table 3: 2 - Principles of Lean Management 53
Table 3: 3 - Techniques and Tools for Mitigating Construction Delay 57
Table 3: 4 - The 4P Model of Lean 66
Table 3: 5 - Lean Principles Applied To Project Management 68

Table 4: 1 - Selection of a Research Philosophy.. 78
Table 4: 2 - Selection of a Research Approach 80
Table 4: 3 Quantitative vs. Qualitative Methodology 84
Table 4: 4 - Selection of a Research Method 86
Table 4: 5 - Selection of a Research Strategy 89
Table 4: 6 - Taguchi's Orthogonal Array 96
Table 4: 7 Chosen Research Design.. 104

Table 5: 1 - Position of the Respondents.. 127
Table 5: 2 - What is your profession? 128
Table 5: 3 - How long have you worked in the construction industry? 128
Table 5: 4 - What is the main activity of your department?.. 128
Table 5: 5 - Did you study any project management course? 129
Table 5: 6 - Evaluate your knowledge of Lean Project Management 129
Table 5: 7 - Benefits of Lean in Design 130
Table 5: 8 - Benefits of Lean in Project Management 131
Table 5: 9 - Benefits of Lean in Organisational Management 132
Table 5: 10 - Lean's Tools & Techniques 134
Table 5: 11 - Impact of Lean Constforction's Tools/Techniques on Performance........................ 135
Table 5: 12 - Barriers of Lean Construction.. 137
Table 5: 13 - Enablers of Lean Construction 137
Table 5: 14 - Lean Project Management and Performance 139
Table 5: 15 - Lean Project Management and Business Strategy 139
Table 5: 16 - Lean project management and Stages of Business Strategy 139
Table 5: 17 - Key Elements in BCC's Construction Projects 143

Table 5: 18 - Project Team Management Plan (SPTMP) ... 147
Table 5: 19 - Approve Budget, Time and Contractor Selection ... 147
Table 5: 20 - Framing ... 147
Table 5: 21 - Windows ... 147
Table 5: 22 - Electrical ... 148
Table 5: 23 - Elevators ... 148
Table 5: 24 - Drywall ... 149
Table 5: 25 - Exterior Casework ... 149
Table 5: 26 - Finishing Project ... 149

Table 6: 1 - Framing ... 156
Table 6: 2 - Windows ... 156
Table 6: 3 - Electrical ... 156
Table 6: 4 - Elevators ... 157
Table 6: 5 - Drywall ... 157
Table 6: 6 - Exterior Casework ... 157
Table 6: 7 - Analysis of Variance for Framing Actual Time ... 158
Table 6: 8 - Analysis of Variance for Framing Actual Cost ... 159
Table 6: 9 - Analysis of Variance for Windows Actual Time ... 160
Table 6: 10 - Analysis of Variance for Windows Actual Cost ... 161
Table 6: 11 - Analysis of Variance for Elevators Actual Time ... 162
Table 6: 12 - Analysis of Variance for Elevators Actual Cost ... 163
Table 6: 13 - Analysis of Variance for Electrical Actual Time ... 164
Table 6: 14 - Analysis of Variance for Electrical Actual Cost ... 165
Table 6: 15 - Analysis of Variance for Drywall Actual Time ... 165
Table 6: 16 - Analysis of Variance for Drywall Actual Cost ... 166
Table 6: 17 - Analysis of Variance for Exterior Casework Actual Time ... 167
Table 6: 18 - Analysis of Variance for Exterior Casework Actual Cost ... 168
Table 6: 19 - Nature of Identified Correlations ... 171
Table 6: 20 - Totals of Identified Correlations ... 171

Table 7: 1 - Improving Framing Construction through Employment of Kanban's Rules ... 177
Table 7: 2 - Improving Windows Construction through Employment of Kanban's Rules ... 179
Table 7: 3 - Improving Electrical Activities through Employment of Kanban's Rules ... 182
Table 7: 4 - Improving Elevators Activities through Employment of Kanban's Rules ... 185
Table 7: 5 - Improving Drywall Construction through Employment of Kanban's Rules ... 187
Table 7: 6 - Improving Exterior Casework Construction through Kanban's Rules ... 189
Table 7: 7 - Actual Time Improvements of Framing Activity ... 193

Abbreviations and Glossary

APM	**Association for Project Management**
BCC	Binladin Construction Company
CIRIA	Construction Industry Research and Information Association
CLIP	Construction Lean Improvement Program
Conceptual Framework	A network or a “plane” of linked concepts.

Cost	The budget that has been established for the construction project.
CPN	Construction production Network
CTP	Cost-Time-Profile
EME	Extended Manufacturing Enterprise
KPI	Key Performance Indicator- is the metric used to evaluate factors that are crucial to the success of a construction organisation.
LCI-UK	Lean Construction Institute-UK
LEA	Lean Enterprise Architecture
Lead Time	The time between the initiation and completion of the project process.
Lean Project Management	The continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project.
LM	Lean Management / Lean Manufacturing
LC	Lean Construction
LPDS	Lean Project Delivery System
LPS	Last Planner System
Model	A graphical, mathematical, physical, or verbal representation or simplified version of a concept, phenomenon or an aspect of the real world.
PDCA	Plan-Do-Check-Act
PMBoK	Project Management Book of Knowledge
PMI	Project Management Institute
PPC	Percent Plan Complete
Project Management	The management discipline that plans, organise and controls people, money and cash so that projects are completed successfully in spite of all the risk.
PROMQACS	Project Management Quality, Cost System
QPMS	Quality Performance Management System
QPTS	Quality Performance Tracking System
Simio	Simulation Modeling Software
Throughput	The amount of materials or item passing through the project process.
WBS	Work Breakdown Structure

Chapter One: Introduction

1.1 Research Background

Construction industries around the world are developing at a rapid rate both in terms of technology and organisation. Apparently, the construction industry earns its reputation from its perceived performance in terms of the value it produces and it also plays a key role in the economy of many nations which is a vital contributor to the gross domestic product (GDP) growth and produces the built environment that supports other sectors of the economy in many part of the world (Oladapo, 2015; Othman, 2013). The construction industry in Saudi Arabia is passing through an unprecedented construction boom in which projects have become extensive, complex and fast moving. Thus, there is a need for more effective project management techniques. Saudi construction companies working with public and private clients recognise the urgency to; improve efficiency, minimise waste, increase productivity and most importantly overcome the problem of 'delay'. This, of course, won't be easy, but may be achieved through better planning and control (Globerson and Zwikeal, 2002; Striprasert and Dawood, 2002; Shtub et al; 2005). Charvat (2003) believes that the poor performance of construction projects can be addressed through better management of the resources and the use of efficient managerial tools and techniques throughout the life of the project, from start to completion. Alsehaimi et al. (2009) also thinks that advanced project management tools can help construction firms to overcome some of their inefficiencies such as delays and resource underutilisation.

This research revolves around Saudi megaprojects. Megaprojects are programs that integrate strategically aligned projects into one very large project (Miller and Lessard, 2000; Jaafari, 2004). They pose both challenges and opportunities in the construction sector, especially in the Gulf countries. Flyvbjerg (2007) reports that megaprojects have a large investment of more than £5 million, extreme complexity, substantial risks, long duration, a large number of participants and extensive impacts on the community, economy, technological development, and environment of the region or even the whole country. In order to deliver projects successfully and construction project management to be improved and effectively, it is important to understand the factors involved in planning, execution and overall management.

Major construction projects are typically characterised by a high degree of complexity, long duration and substantial costs (Doloi et al., 2012). Execution of construction projects often involves numerous parties and a large variety of interconnected and interdependent activities. That's why even when construction activities are well-planned and due consideration is given to all possible risks, undesirable incidents or events can happen unexpectedly and obstruct the execution of construction plans or strategies. Such incidents could lead to major delays which wouldn't only undermine the operational performance of construction firms, but also have an adverse impact on the performance of other stakeholders (Ahsan and Gunawan, 2010). There are various reasons to which delays in construction projects may be attributed. Their impact on operating performance may be direct or indirect, and they might appear concurrently or subsequently (Alsuliman, 2019). Regardless of the nature of their occurrence, there is a direct link between delays on the one hand and higher costs and more frequent conflicts between project stakeholders on the other hand (Senouci et al., 2016). Understandably, when a project slips over its planned schedule, all involved parties incur cost. Project owners lose revenues from lack of production facilities, while contractors incur higher overhead costs due to longer project duration, higher labour expenses and underutilisation of equipments and machineries. Nevertheless, major construction projects are rarely "completed within the specified time" Assaf and Al-Hejji, 2006, p. 349).

However, although it is not uncommon for large construction projects to slip over schedule, it doesn't mean that project managers should underestimate the importance of project schedules. Schedules are the benchmark against which a contractor's performance is measured (Wang et al., 2018). In fact, managers can't monitor or control projects without schedules (Zavadskas et al., 2014). Poorly controlled project schedules are typically associated with cost overruns and substandard project quality (Sinesilassie et al., 2017; Agyekum-Mensah et al., 2017). There have been numerous investigations into the use and benefits of project schedules as a means of controlling and managing delays (e.g. Santoso and Soeng, 2016; Mpofu et al., 2017). Most of these studies investigate the problem of delay in the construction phase rather than in the pre-construction stages (e.g. Ballesteros-Pérez et al., 2015). It is generally understood that the passage from one phase to another is not all "smooth-sailing", but is fragmented, complex and uncertain (Arayici et al 2012; John et al, 2005). The cost of uncertainties is not always taken into account, especially in smaller construction firms (Cavignac, 2009). Uncertainties cause delays, decrease throughput, increase cost and lead to a poorer quality end product. Thus, it is very important that uncertainties are considered and addressed as they appear. The main aim of construction project management is to help the key stakeholders in a project to meet their commitments and minimise negative impacts on construction project performance in relation to cost, time and quality objectives (Banaitiene, et al. 2011).

Moreover, synthesis of previous studies on delay in various countries reveals that poor project management is one of the main reported reasons for construction delay i.e. the project execution (Odeh and Battinah, 2002; Abdul-Rahman et al., 2006; Assaf and Al-Hejji, 2006; Sweis et al., 2007; Ikediashi et al, 2014; Alghonamy, 2015; Mahamid et al, 2015). In other words, due to uncertainties the planning and implementation stages are never the same. In addition, several authors (e.g. Aina and Wahab, 2011; Olusegun and Michael, 2011; Oyewobi et al., 2011; Windapo and Olusegun, 2010) have identified these problems without practically solving them. For example, in these studies, delays are frequently attributed to poor project management, which has been identified as the most often repeated causes of delay. Firms' failure to achieve optimal operational performance is commonly attributed to ineffective planning and control, poor site management, ineffective communication and coordination between the parties involved, delay in materials delivery and late procurement of materials. In order to improve performance, this research argues that the impact of such controllable causes of delay might not overcome using traditional management techniques. Instead, construction firms should consider the adoption of 'Lean Management' (LM).

Lean project management advocates collaborative production planning while emphasising on the reliability of workflows, promotion of pull-based culture and an open communication system (Ballard et al., 2007, Mossman, 2013). It also promotes trust and transparency with the main aim of maximising customer value and improving the performance of the industry (Howell and Ballard, 2000; Ballard et al 2009; Ballard et al 2002; Alsehaimi et al., 2009). There are numerous reports in the literature that the tools and techniques of Lean management have helped construction firms optimise their operational efficiency and to improve their performance (Alarcon et al., 2005; Thomas et al., 2003; Al-Aomar, 2011). For example, the Lean Construction Institute has developed what's today known as Last Planner System (LPS) and Lean Project Delivery System (LPDS) which are based on the principles of LM and are designed to help construction firms to improve quality, lower costs and make more effective use of their time and resources (Pinch, 2005).

1.2 Research Problem

This research focuses primarily on the problem of delay because delay is a major contributor to Saudi construction firms' underperformance. Ramanathan et al. (2012) defined delay in the context of construction projects as a "situation when a task or activity, process or project is executed over a period ending at a time beyond the planned end time". It is quite common for construction projects go over-budget and to experience a lot unanticipated delays in Saudi Arabia (Albogamy et al., 2012). Alzara et al. (2016) reported that at least "70% of Saudi public projects" experienced delays due to contractors' failures to establish accurate timelines and also due to their inabilities to deploy their resources efficiently. This problem starts as early as the planning phase and continues throughout a project's lifecycle (Assaf and Al-Hejji, 2006). It has a variety of causes, including culture (Mellahi and Demirbag, 2011).

Culture has a significantly important role in shaping workers' attitudes and behaviours, especially in multicultural teams. In Saudi Arabia, construction project teams almost always comprise people from different national, cultural, ethnic and religious backgrounds. Diversity in backgrounds means diverse attitudes toward delay and differing opinions on how to best manage project schedules (Ali, 2008; Assaf and Al-Hejji, 2006). Aziz and Abdel-Hakam (2016) explored the causes of delays in road construction projects in Egypt using interviews and a questionnaire. They identified 293 delay causes from a detailed review of construction literature and examined their impacts on road project's completion. Inefficient deployment of resources and poor management of construction operations were found to be two of the most prominent causes of delays. Another study by Noman et al. (2018) investigated the causes of delays in Saudi construction projects. Their investigation included a review of 662 projects with a total value of approximately 40bn Riyals. The study found that nearly all the projects experienced delays, and that contractors' poor technical and material capabilities were the primary causes of delay for around 82% of the projects. They also found that 12.2% of delays were attributed to administrative and regulatory issues.

Unfortunately, it is not always clear who is responsible for the delays in construction projects (Alzara et al., 2016). It is common for owners to blame contractors for delays and vice versa. Contractors typically blame projects' owners for taking too long to make decisions about design changes or modifications (Alzara et al., 2016). Another study by Al-Kharashi and Skitmore, (2009) investigated the causes of delays in the context of the Saudi construction industry and found that delays undermine the financial performance of both, focal companies and contractors. In other words, it is in the best interests of all parties for construction projects to be completed in time. However, that's not always possible due to several factors. Al-Kharashi and Skitmore, (2009) identified a range of 131 factors which they found to cause delays in construction projects and divided them into four categories; namely, consultant-related factors, contractor-related factors, owner-related factors, and irregular causes.

Furthermore, Mahamid (2013) studied schedule delay in public construction projects in Saudi Arabia. His investigation found that project owners played a significantly influential role in the management of project timelines. For example, project owners' failure to pay contractors on time was found to be a major contributor to unnecessary delays. Alzara et al. (2016) stated that around of "87% of projects" were typically extended due to project owners' failures to meet their managerial and financial obligations. Another study by Assaf and Al-Hejji (2006) examined the causes of delays in major construction projects. They found that major projects were typically delayed because of: (1) unplanned design changes/modifications, (2) owners' failure to review and approve project documents in time, (3) and owners' decisions to suspend construction activities temporarily. Other relevant causes of delay include; ineffective or poor decision-making processes, lack of skills, inaccurate estimations, poor planning, inefficient schedules, lack of training, conflict of interests, poor working conditions, lack of resources, poor supervision, ineffective site management, and cash flow problems (Alzara et al., 2016).

It appears that traditional construction project management tools and techniques have become impotent and inconsistent with the needs of today's construction firms. Kang et al (2015) claims that although traditional project planning approaches facilitate multi-project planning, they rely on deterministic activity task durations and do not support what-if analysis without which the casual relationships among the different activities and associates constraints can't be understood. In large, complex, and uncertain environments, it is usually very difficult to consistently allocate scarce resources efficiently without performing what-if analysis due to lack of adequate information (Pitch et al, 2002). According to Zilicus Solutions (2012), the main elements of project planning are time, quality and resource, known as TQR constraints. These dimensions are critical for project success, but are always under risk. Any uncertainties associated with TQR are a risk to the project scope and the same time any change in the scope has a direct effect on either all or any of time, quality and resources of a given project. Hence, it is important that effective project planning and control tools and techniques are adopted and utilised to ensure optimal management of time, cost, quality and resources. The principles, practices and systems of Lean Construction (LC) are said to offer a viable means of dealing with contemporary challenges in the construction industry. Unfortunately, studies that investigate the adoption of LC in the Saudi construction industry are scarce or nonexistent. In an attempt to fill this gap in the literature, this research set out to explore the applications, the potential benefits and implications of Lean's Kanban's adoption in the context of Saudi construction firms especially in terms of Kanban's impact on performance. It develops a Lean project management framework for Saudi construction firms in order to improve the time and cost efficiencies of their construction operations.

1.3 Research Motivation

Operational inefficiencies in general and delays in particular are quite common in the Saudi construction industry. I have observed, over the years, how the industry has failed to address the root causes of its inefficiencies. Despite its rapid growth and modernisation, the industry still suffers from mismanagement and inadequate utilisation of contemporary systems. This has hindered the industry's ability to overcome many of its problems. For example, although time and cost management are often prioritised, project managers still struggle to prevent cost overruns and delays. This is probably due to their short-sighted management approach that pays greater attention to the management of expenses than to the elimination of non-value-adding activities (i.e. waste) such as idle time, overprocessing and excess materials. Also, the concept of preventative action is almost nonexistent in the Saudi construction industry. It is quite common for Saudi firms to fail to prepare well-thought plans and strategies to address unanticipated risks, incidents or problems. In other words, a reactive rather than a proactive approach to management is normally used to manage the day-to-day construction activities.

Moreover, the use of traditional management systems has hindered Saudi firms' abilities to establish more effective management processes and procedures. For example, contractors are rarely invited to participate in the planning and development phase, and their involvement is restricted to the construction phase and its associated activities. This outdated approach to construction management results in many missed opportunities and overlooks the contractors' valuable practical insights which are crucial for the development of realistic project plans. It also hinders project owners' abilities to take preemptive actions to prevent costly delays.

It's my desire to help the Saudi construction industry to address the aforementioned problems that motivated me to undertake this research. My discontent with the way Saudi construction firms managed their operations and their failures to address their operational inefficiencies had influenced my decision to focus on this particular area of research. My intention was to find a contemporary management theory, approach or method that would help Saudi construction firms to reduce time and cost and to improve their operational efficiency. Lean's Kanban offered just that. Several empirical studies have reported that the adoption of Lean's tools and techniques has helped construction firms to improve their performance (e.g. Thomas et al., 2003; Gonzalez et al., 2010). Lean management is made up of five principles; namely: (1) specify value; (2) identify the value stream; (3) create a flow for the value (4) pull and (5) perfection (Womack and Jones, 1996). Its tools and techniques include: visual management, daily huddle meetings, 5S, first run studies, last planner system, Kanban, etc. (Salem et al., 2005). It comprises practical improvement initiatives whose purpose is to minimise waste of material, time and efforts, while generating the maximum amount of value (Mossman, 2013). This study doesn't only explore the benefits and implications of Lean construction, but also simulates Kanban's impact on the Binladin Construction Company' performance using Simio 10 simulation.

1.4 Research Questions

The development of the research question involves a process of examining an issue, in an area of interest and which might pose a problem (Lipowski, 2008). As a result of these issues identified in section 1.2, the following research questions have been formulated.

- What are the operational challenges that construction firms in general, and Saudi construction firms in particular are facing?
- What are the project management tools and techniques which construction firms in general and Saudi construction firms particular use for planning, control and management of construction activities?
- What are the factors that undermine the performance of construction firms?
- How could the principles of Lean construction help Saudi construction firms to address their operational challenges, especially in relation to the cost and delay?
- What are the implementation enablers and barriers that have been experienced by Saudi construction firms when trying to implement Lean construction techniques?

- What are the benefits and operational implications of Lean construction adoption in the context of Saudi construction firms?
- How the adoption of Lean construction's tools and techniques could affect the operational performance of construction firms?

This research uses operational scenarios from the Binladin Construction Company in Saudi Arabia to validate the proposed Lean project management framework.

1.5 Research Aim and Objectives

This research aimed to:

- Develop a Lean project management framework for the construction companies in order to improve the time and cost efficiencies of their construction operations.

To achieve this aim, the author needed to achieve the following research objectives:

1. To identify the operational challenges faced by Saudi construction firms related to cost and time overruns through critical literature evaluation.
2. To evaluate the efficacy of traditional project management tools and techniques in terms of helping construction firms to reduce costs and prevent unnecessary delays through critical analysis of relevant, peer-reviewed publications and through semi-structured interviews with construction project management practitioners.
3. To identify the main factors, benefits, barriers and enablers of Lean construction through both semi-structured interviews and close-ended questionnaire.
4. To examine the synergies, which exist between the principles of Lean management and construction project management practices by analysing the current state of the Saudi Binladin Construction Company using process mapping, Discrete Event Simulation (DES) and Taguchi orthogonal arrays.
5. To improve the current state of Binladin Construction Company's operations with a focus on time and cost efficiencies using Lean tools to develop the framework.

1.6 Scope of Research

This research aims to develop a Lean project management framework which could be used by construction firms to improve the time and cost efficiencies of their construction operations. In order to achieve this aim, the author first set out to identify the operational challenges faced by construction firms with a focus on the main and most common causes of cost and time overruns. He then initiated an empirical investigation to assess the efficacy of traditional project management tools and techniques in terms of helping construction firms to reduce costs and prevent unnecessary delays. The investigation has also enabled the author to identify the most common benefits, barriers and enablers of Lean construction practices in the context of Saudi construction firms. The investigation entailed a detailed assessment of the current state of the Binladin Construction Company. The assessment process involved the use of process mapping, Discrete Event Simulation (DES) and Taguchi orthogonal arrays. These tools also enabled the author to examine synergies which exist between the principles of Lean management and construction project management practices. The outcome of the assessment process highlighted areas of improvement and illustrated how Lean's Kanban could be used by Saudi construction firms to improve their operations' time and cost efficiencies.

It is important to note that this research did not study all of the factors which hinder Saudi construction firms' abilities to achieve optimal operational performance. Instead, it focused primarily on the problems of cost and time overruns. It explored the possibility of integrating Lean and project management practices under the banner of Lean construction as a means of solving some of the Saudi construction industry's most persistent problems. Moreover, this research was based mainly and solely on the experiences and operational context of a single Saudi construction firm - Binladin Construction Company (BCC). The author chooses to investigate BCC because it has been awarded many of Saudi Arabia's major construction projects, so the company's profile fit very well with the needs of this research. Besides, BCC is more likely to embrace the tools and techniques of Lean construction than other Saudi construction firms due to the size of its operations and its keenness to maintain high operational standards. Furthermore, this research pays greater attention to the construction phase than the pre-construction stages such as planning and development. This means that pre-construction factors that impact on firms' performance haven't been considered in this research. Also, this research is primarily focused on the Saudi construction industry and no attempts have been made to consider the contexts of other countries. Thus, the findings are context-specific and may not be applicable or transferable to other industries or countries. This research's scope also excluded the roles played by sub-contractors in shaping the operational performance of focal companies. Only the experiences and operational context of focal companies have been considered.

1.7 Contributions to Knowledge

This research makes several valuable contributions to knowledge. These include:

1. This research is one of the few studies that examine the impact of Kanban's 6 rules' adoption of the operational performance of construction firms (e.g. Koskela, 1992; Ogunbiyi et al. 2014; Ko and Kuo, 2015; Xing et al., 2020). There are many studies that investigate the impact of Lean's implementation on construction firms' performance, but studies that explore the impact of Kanban's adoption on the cost and time efficiencies of construction activities are scarce. From the onset, the author set out to find a contemporary management theory or a system that can help Saudi construction firms to solve the problem of time and cost overruns. Lean's principles and Kanban's rules in particular offered just that. Hence, this investigation has not only explored the benefits and implications of Lean construction, but also simulated the impact of Kanban on the performance of BCC.
2. This research contributes to the project management literature as it considers the use of contemporary Lean management tools and techniques as a substitute to the outdated management methods and techniques to achieve better results. In fact, this study is one of a few empirical investigations that explore the synergies that exist between Lean management and project management. It also contributes to the Lean construction literature as it explores the experiences of a Saudi construction firm with the adoption of Lean's tools and techniques.
3. This research also contributes to the ongoing debate about the applicability of Lean's principles and techniques to the operational context of the construction industry. Besides, this research doesn't only investigate the benefits, implications, enablers and barriers of Lean construction, but it also advocates its diffusion among Saudi construction firms. It encourages construction firms and project managers in particular to appreciate the many benefits of Lean construction.
4. This study simulated the potential of Kanban and found that the adoption of Kanban's rules would help Saudi construction firms to reduce delays and optimise their operations' efficiency. It found, for example, that conventional construction logistics, lack a flow view and the ability to rapidly and precisely acquire data that's needed to optimise planning activities, control systems and logistical operations. To overcome these problems, firms would need to embrace Kanban's six rules and switch from

push-based logistics systems to pull-based systems which involve real-time monitoring of consumption and demand-triggered replenishment.

5. This research investigated the nature of the relationship between the cost and time of construction activities on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand using the Minitab software. Interestingly, the results indicate that the 'processing time' is the single most influential variable in terms of its impact on the cost and time efficiencies of construction activities. This means that improving the Leanness of 'processing time' will help Saudi firms to reduce cost and time overruns notably.
6. This research has discovered that the success of Lean construction initiatives depends heavily on senior management's commitment and motivation to allocate the needed resources and the right personnel to the implementation teams. It has also discovered that cultural resistance, short-sighted investment policies, lengthy implementation, managers' impatience, complexity and lack of workers' buy-in were significant barriers to Lean construction practices' adoption.

1.8 Research Novelty

There are many elements in this research that make it novel. Firstly, this research is centred on the use of Kanban's six roles of management to address the problem of delay in the Saudi construction industry. The idea of using Lean's tools and techniques for construction project management is not new at all, but what makes this study novel is that it contributes to a very niche and an underdeveloped research subject in the field of construction management. Its findings advance our understanding of not only the benefits, enablers and barriers of Lean construction adoption, but also of how Lean's Kanban may help address the problems of delays and cost overruns in construction projects.

Secondly, this research has attempted to address the shortcomings and limitations of traditional project management tools and techniques which are still widely used in the Saudi construction industry. It proposes a contemporary project management framework that incorporates Kanban's six roles of management into the management processes and systems of construction projects. The framework, focuses more on what really needs to be done in order to improve firms' operational efficiencies than on the lifecycle of adoption processes. It is problem-oriented and facilitates the development of well-thought action plans that can be used to identify and eliminate operational inefficiencies.

Thirdly, this research contributes to the project management literature as it considers the use of contemporary Lean management methods as a substitute to the outdated management techniques to achieve better results. In fact, this research is one of a few studies that examine the synergies between Lean management and project management. It also contributes to the ongoing debate about the applicability of Lean's tools and techniques to the operational context of the construction industry, and advocates their adoption and implementation by construction companies.

1.9 Overview of Research Methodology

Research methodology refers to "systematic and orderly steps taken towards the collection and analysis of data" (Collis and Hussey, 2003). This research methodology is based on the components of Saunders et al.'s (2016) research onion. In terms of philosophy, the researcher embraced the assumptions of both positivism and interpretivism (*Refer* to Section 4.4). He believed that the use of a 'hybrid research philosophy' would allow him to successfully achieve this research's aim and all of its associated objectives. Interpretivism is subjective in nature and allows researchers to study complex social phenomena using people's shared meanings and experiences, whereas positivism is based on objectivism and only accepts what can be scientifically verified. Having a mixed philosophical stance has enabled the author to use both a quantitative questionnaire and qualitative interviews to collect primary data from participants. This has provided both rigour and depth of analysis, which would not have been possible without a mixed research philosophy.

In terms of theory development approach, this research adopted 'abduction' which enabled him to move flexibly and freely between induction and deduction ((*Refer* to Section 4.5). The objective approach has enabled the author to tap into the strengths of both induction and deduction. Abduction is useful for research studies like this one where there is a need to explore the unique issues with little or no pre-existing research/knowledge as well as pre-researched subjects simultaneously. Induction enabled the author to explore the current challenges and the limitations of conventional project management practices in the context of Saudi construction firms using interviews, whereas a deduction enabled him to identify the most common enablers, drivers, benefits and barriers of Lean construction using a questionnaire survey. Abduction has proven to be very effective in helping the author to evaluate the extent to which Kanban's 6 rules' adoption typically affects the time and cost efficiencies of different construction activities.

In terms of methodological choice, this study adopted a mixed-method research design that combined qualitative with quantitative research methods and techniques (*Refer* to Section 4.6). This methodical choice fit very well with this research's data collection and data analysis requirements. The author needed to employ both quantitative and qualitative data collection and analysis tools and techniques to be able to achieve this study's aim and objectives. The qualitative data were collected using interviews and was analysed using thematic analysis, while quantitative data was collected using a survey and analysed statistically using MS Excel.

In terms of strategy, this research combined three strategic approaches, namely experiment, survey and case study (*Refer* to Section 4.7). The experimental strategy was adopted mainly because it enabled the researcher to simulate the impact of Kanban's adoption of the operational performance of the Binladin Construction Company particularly in relation to cost and time efficiencies. The Discrete Event Simulation process involved the employment of computer software to simulate the impact of Kanban's rule's adoption on performance using Minitab and Simio 10 computer software. Moreover, the survey strategy was also consistent with the needs of this research. It was adopted because it enabled the author to collect data from a large group of construction workers in Saudi Arabia. The author had to use a survey to study workers' perceptions about the most common enablers, barriers and implications of Lean construction's implementation in the context of Saudi firms. Lastly, the case-study strategy was used because it helped the author to investigate the operational reality of the Binladin Construction Company.

Refer to Chapter 4 for more details about the chosen research methodology.

1.10 Thesis Structure

This thesis comprises ten chapters, each having an introduction and summary. The design of the chapters is intended to capture the flow of information about the key issues. Hence, each chapter leads into the development of an important part of this research.

Chapter One: 'Introduction' presents the background to the research problem, research aim and objective. In addition to the research scope and motivation, this chapter highlights the contributions of this research. Finally, the research methodology section provides a brief overview of the steps that had been taken to achieve this research's aim and objectives.

Chapter Two: 'Literature Review - Project Management' presents a detailed review of the primary research problem. The first part of this chapter starts with an overview of the nature and characteristics of the construction industry in general and the Saudi construction industry in particular. It then discusses the most common causes of delay in construction projects. It also outlines the types of delay and its impact on performance. The second part of this chapter provides a brief introduction to project management and examines the role of project managers. It also discusses the importance of project management and explains its processes. It provides a brief insight into project management tools and techniques and also outlines the key issues project managers have to deal with in the construction industry. It ends with a discussion on the theoretical basis of project management's theories and concepts.

Chapter Three: 'Literature Review - Lean Construction' introduces Lean tools, techniques and principles. It provides an insight to the concept of Lean construction and discusses the applicability of Lean's tools and techniques in the construction industry and highlights the benefits and challenges commonly associated with the implementation of Lean construction's tools and principles. It also reviews existing Lean construction frameworks and their potentials to improve firms' operational performances.

Chapter Four: 'Research Methodology' describes the research methodology that has been adopted for this research study. It evaluates, discusses and justifies the scientific methodological steps that the author has taken in order to successfully achieve the aim. It also introduces Design of Experiments (DoE) and Discrete Event Simulation (DES) and details how they have been used to simulate the potential benefits and implications of adopting Kanban's rules by the Binladin Construction Company / BCC.

Chapter Five: 'Data Analysis & Interpretation' presents the outputs of data analysis and interpretation processes for the primary data which has been collected using interviews and questionnaires. It starts with the data from the interviews. It presents, interprets and discusses key interviewees' most important statements. The second part of this chapter analyses and discusses the results of the quantitative questionnaire.

Chapter Six: 'Assessment of Current State' presents and discusses the outputs of an assessment of the current state of the operational performance of the Binladin Construction Company / BCC. It demonstrates how the Minitab software has been used to organise and analyse the relevant data. ANOVA analysis in particular has been used to explore the nature of relationships between the different research constructs.

Chapter Seven: 'Kanban-Facilitated Improvements' demonstrates how the adoption of Kanban's rules could help the Binladin Construction Company / BCC to improve its operational efficiency in general and to reduce delays in particular. The results presented in this chapter are based on the data which was collected from the case-study firm and consequently on the design of experiment (DoE). They are also based on discrete event simulations (DES) of BCC's current state and Kanban-facilitated improved state.

Chapter Eight: 'Discussion' demonstrates how the aim and objectives have been achieved. It highlights the research's key findings and discusses them in light of the relevant academic literature. It summarises and evaluates the findings of the empirical investigations and experiments as well as the output of SIMIO 10 simulation of Kanban's impact on the performance of the Binladin Construction Company. It also provides a justification for the use of simulation models to simulate the impact of Kanban's adoption on the time and cost efficiencies of construction activities using real-life scenarios.

Chapter Nine: 'Conclusions and Recommendations' summarises the research's main findings and demonstrates how the research's aim and objectives have been successfully achieved. It presents the outcome of his exploratory investigations.

Chapter 2: Literature Review - Project Management

2.1 Introduction

This chapter comprises two main parts. The first part presents a detailed review of the primary research problem - delay. It starts with a brief overview of the nature and the characteristics of the construction industry in general and the Saudi construction sector in particular. It then discusses the most common causes of delay in construction projects. It also outlines the types of delay and its impact on performance. It ends with a comparison of the types and the impact of delay by country.

The second part presents the output of a review into project management literature. It starts with an introduction into projects and project management. It then examines the role of project managers and discusses the importance of project management before going over the process of project management. This is followed by a discussion about the definitions and characteristics of project management in the context of construction. It also provides a brief insight into project management's tools and techniques, and it outlines the main elements of project management and the key issues project managers have to deal with in the construction industry. It ends with a discussion on the theoretical basis of project management theories and concepts.

2.2 The Nature of the Construction Industry

Hook and Winton (2016) reported that construction is likely to be one of the most dynamic industrial sectors in the next fifteen years and is utterly crucial to the evolution of prosperous societies around the world. For instance, large projects spending globally are expected to total more than $9 trillion by 2025, up from $4 trillion in 2012 (Oxford Economics, 2014). However, larger projects tend to exhibit serious issues due to the increased cost, delays, resource allocation, supplier engagement and other uncertainties (Kang et al, 2015). Construction projects are often interactive and complex endeavours (Kanapeckieni et al, 2010). As a result, the construction industry has become more specialised and sophisticated in terms of project delivery i.e. in order to deliver these complex and large projects, activities are segregated between a larger number of subcontractors instead of one master builder (Kent and Becerik-Gerber, 2010). For instance, large project worth (between 20-25 million GBP) a principal contractor may be managed by over 70 other sub-contractors, where a large percentage of smaller than (50,000 GBP) or less (HM Government, 2013). This method appeared to be as a result of multi-cultured industry experience which affect the efficiency, fragmentation and high cost of unsatisfactory heterogeneous interplay (Gallaher et al, 2004). These challenges introduced construction and management around 1960’s as a as a mitigation option to the challenges. Construction management is a discipline that facilitates successful execution of the various stages of projects on behalf of their owners (Walker, 2002).

The activities of the construction sector are numerous with key regulation, planning, manufacture, design, structuring and maintenance of buildings and other operations (Burtonshaw-Gunn, 2009). Examples include residential buildings, bridge erection, roadway paving, excavations, demolitions, large scale painting jobs, setting of fixture accessories and construction finishes of works. Consequently, the construction sector comprises of engineering, construction and building of structures which includes the progression-plant of the project (Ashworth, 2010). Figure 2:1 show a usual construction project being developed and under work-in-progress.

Figure 2: 1 Dynamism of a Typical Construction Project in Jeddah, Saudi Arabia
Source: Al-Hudhaif (2016)

Murdoch and Hughes (2008) asserted that the construction industry is wide and as such most of the people who work in the industry is doing so willingly and also based on their professional background. In so doing, the industry has drawn many branches and specialist in architecture, surveying, electrical, mechanical and structural engineering, among others. According to Eccles (1981), the term construction in a broader context, is described as "erecting structure, maintenance, land development, repairs of abandoned structures and the demolition of unwanted and dilapidated structures such as shops, houses, offices, bridges, dams, roads, factories and airport extensions and chimneys,". Although firms carry out work related to their specialised area of industry interest, few firms are limited to a confined type of one technology within the industry in a narrow scope. The construction industry and the challenges associated with the industry is difficult to be understood as the relationship between the parts are unclear and the boundary of the industry is also indistinct. Due to the involvement of stakeholders at different levels of construction project increases the uncertainties and hence project management complexities (Murdoch and Hughes, 2008). Barrie and Paulson (1992) ascertained the insertion that the construction industry must clearly include a specified general and Specialty construction to clear ambiguity about what the construction industry means to a layman term. They added that the scope in the industry need to be more expatiated to include material supply, manufacturing equipment, and designers of facilities.

2.2.1 Characteristics of the Construction Industry

Shirazi et al (2007) reports that the construction industry is mainly about the management of distinguished responsibilities at the construction site levels. Consequently, researchers have augured that construction is fundamentally a site-limited project-based activity (Cox and Thompson, 1997; Ren and Lin, 1996). Nevertheless, according to Du Plessis (2007) construction can be interpreted as the business of construction, and a comprehensive project cycle in addition to being a site level activity. This indicates that construction can be translated differently and for different purpose other than site activity.

The construction process itself is a complex combination of accurate communication, skill in planning, design, and building skills all directed by knowledgeable project management (PBDC, 2011). This research will be looking to improve planning and control in the construction project management process through the use of Lean in the Saudi Arabian construction industry, since they make key contributions to the overall project success and particularly need improvement in terms of efficiency and effectiveness (Refer to Section 2.7.1 for discussion). According to Muse (2015), the construction industry is a large contributor to countries' gross domestic product (GDP) and is recognised as having a significant multiplier effect on national economies. Figure 2:2 illustrates the extent to which the industry contributes to the economic output of different countries.

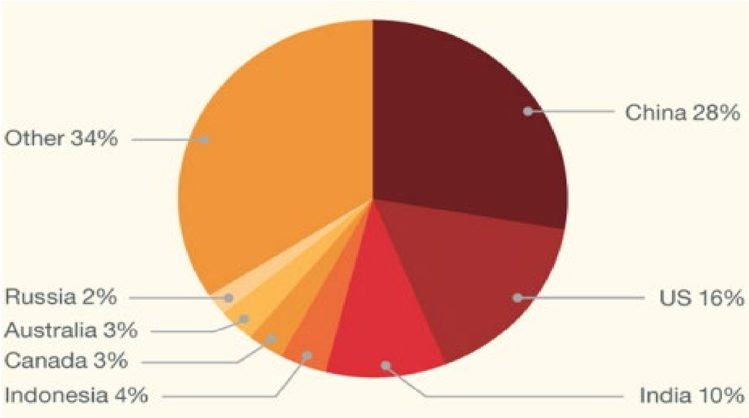

Figure 2: 2 Economic Contributions of Construction Industry in Different Countries
Source: Muse (2015)

According to the Global Construction Perspectives and Oxford Economics (2015), the volume of construction output will grow by 85% to $15.5 trillion worldwide by 2030 with average global construction growth of 3.9% pa to 2030, outpacing that of global GDP by over one percentage point, driven by developed countries recovering from economic instability and emerging countries like Saudi Arabia continuing to industrialise. Accordingly, the potentials for Saudi Arabian construction remains economic benefits as the industry's productivity value is expected to increase at a CAGR of 7.05% by 2020, compared with 6.35% in the past years of (2011-2015) (Timetric, 2016).

The construction industry is associated with characteristic features, which differentiate it from other industries; such unique features include the fragmented nature, one-off projects, and multi participants. According to Harvey and Ashworth (1993), there are certain features of the construction industry, which makes it unique among other industries. Also in construction, the product is often fixed, and the process moves during the construction process, which is opposite to manufacturing or service sector (Harvey and Ashworth, 1993; Thomassen, 2004). The job is usually carried out at the site mostly the client's premises, i.e. the construction designated site (Fellows et al, 2002).

The Saudi Arabian construction sector has several characteristics which distinguishes it from others construction industries across the world (Al-Saqer, 2001), some related directly to the public sector system and others to the country as a whole. They include:

- After the oil industry, the construction industry is the second largest in terms of money spent and volume. The government is the principal source of construction expenditure in Saudi Arabia, accounting for approximately 67% of the nation's construction investment.

- In Saudi Arabia, the building sector has grown at a much faster rate than other sectors and the expenditure on civil buildings is much higher than all other projects in the industrial, mechanical and electrical sectors (MOP, 2008).

- Three primary concerns of owners are cost, quality and time of completion. Many contracting firms are smaller in sizes and therefore not financially stable. A lot of the construction projects use subcontractors, whereby specialised skills accomplish a bulk of the work (Alsedairy, 2001).

- There is poor innovation in the public construction industry and there have been few attempts to undertake any form of improvement initiatives within the sector (Alsedairy, 2001; Abdul-Hadi et al., 2005).

- Saudi construction struggles with numerous problems particularly in planning and control, productivity, innovation, slipping schedules, rework, mistakes, disputes and construction costs. These problems were discovered to be among the major reasons project delays (Al-Ghafly and Al-Khalil, 1995; Al- Khalil and Al-Ghafly, 1999; Al-Saqer, 2001; Alsedairy, 2001; Assaf et al., 2002; Bubshait and Al-Juwairah, 2002; Falqi, 2004; Abdul-Hadi et al., 2005; Assaf and Al-Hejji, 2006). Among the major causes of delay noted by these studies were those related to poor project management, particularly deficiencies in planning and control processes, poor site management and weaknesses in procurement and the supply chain.

It is the focus of this research to manage these wait time wastes or delay in the preparation and control processes of structure developments, thereby improving the delivery procedure of construction projects in the Kingdom of Saudi Arabia. This will be achieved by establishing Lean project management framework that will help improve the throughput and reduce lead time and cost.

2.2.2 Overview of the Saudi Construction Industry

According to the Royal Embassy of Saudi Arabia (2016), the kingdom of Saudi Arabia is the largest country in the Arabian Peninsula and the Gulf region and making it an important country in economic prospects. According to Figure 2:3 The Kingdom of Saudi Arabia, is located between Africa and mainland Asia, with a long coastline on the Red sea and the Arabian Gulf, with Suez Canal near its north-west border (MoC and I, 2004). Saudi Arabia's has a small population of about 27 million, including that of 8.4 million foreign residents

(2010 census), and its capital city is Riyadh. Saudi Arabia's geography is diverse, with forests, grasslands, mountain ranges and deserts. The climate varies from region to region. Temperatures can reach over 110 degrees Fahrenheit in the desert in the summer, while in the winter temperatures in the north and central parts of the country can drop below freezing. Saudi Arabia gets very little rain, only about four inches a year on average (Royal Embassy of Saudi Arabia, 2016).

Figure 2: 3 Map of Saudi Arabia
Source: Info (2016)

Saudi Arabia has oil as the main pillar of its economy and its principal source of revenue, accounting for about 90% of all export proceeds and 45% of GDP (MOP, 2008). Saudi Arabia is the largest exporter of oil in the world and has the largest economy in the Gulf region and the Arab world. The oil has been fully exploited since the 1950s and has transformed the country, which now has excellent infrastructure (Saudi Arabia Economy, 2016). Saudi Arabia is the largest market in the Middle East for construction work, ahead of Turkey, Iran and neighbouring Gulf countries. The construction industry contribute an important element for economic development of Saudi Arabia and is ranked second after oil in the Kingdom's economy and contributes approximately 8% of total GDP and is one of the largest employers estimated to be more than (1.5 million workers) and a major user of industrial and facility goods (MOP, 2008; NCB Economist, 2003). Hence, the state and effectiveness of this sector are critical to the economy of Saudi Arabia. The large infrastructure development ingenuities throughout the last period have provided an opportunity for the construction sector to undertake several large projects.

According to a report from Timetric's Construction Intelligence Center (2016), the industry is set to rise from a value of $105.6 billion in 2015 to $148.5 billion in 2020, measured at constant 2010 US dollar exchange rates. However, the shocks from the current oil slump will still be felt as the total construction contractor awards in the kingdom across the construction sectors are estimated to decrease to $55 billion in 2016 (Abdel-Razzaq, 2016). Regardless, the building sector is forecast to record the highest contractor awards worth $30.5 billion in 2016 with strong growth expected for the infrastructure sector as well. Consequently, Abdel-Razzaq (2016) reports that despite the slowing economy, a shortage of homes available for the country's rapidly growing population means that there are opportunities for developers. Hence, Saudi Arabia will need more than three million new housing units by 2025 to keep up with the demand of rapid population growth, which is expected to hit 37 million over the next 10 years.

Figure 2:4 shows the location of the aforementioned cities in the map of Saudi Arabia

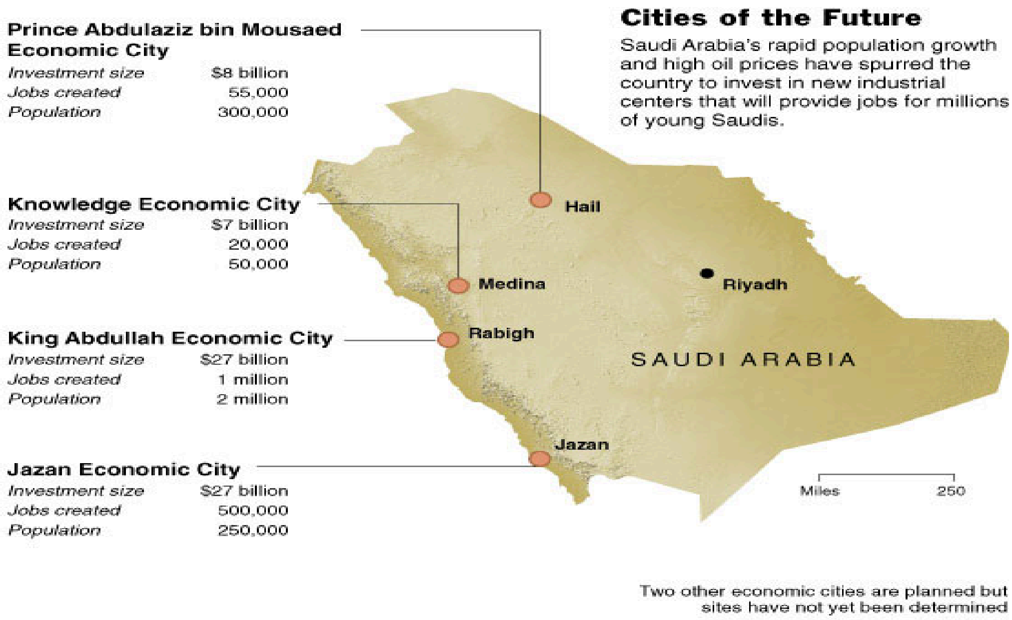

Figure 2: 4 Locations of the Saudi Economic Cities
Source: SAAB (2007)

Due to the outstanding impact the construction sector has on the growth and development of economy, society and environment, growing the performance of construction projects has developed a significant purpose of countries ambitious to follow the footpath towards sustainable development (Mustow, 2006). The construction industry in Saudi Arabia is passing through an unprecedented construction boom in which projects have become extensive, complex and fast moving. Consequently, it has become essential for modern, efficient project management techniques. Construction organisations, working with public and private sector clients, have to find ways to improve management efficiency, reduce waste, increase productivity and thus control delay.

2.3 Performance of the Saudi Construction Industry

The construction industry in Saudi Arabia has been through significant change stages and has been in fluctuation since the 1980s due to large infrastructure projects and there has been a high level of competition between different contractors to win projects, even though profit margins are low. Moreover, there has been an increasing demand for construction projects of different types and this, together with tight budgets, has given the construction industry an extra challenge to reduce costs. The delinquent of high expenses of in all areas of construction is increasingly becoming a problem. Therefore, one of the most pressing matters for the construction sector in the Kingdom of Saudi Arabia has been to recognise the main issues that lead to these high construction costs so that changes can be focused on those factors to try and decrease them.

Saudi Arabia has been under pressure to improve the performance and productivity of construction projects mainly due to competition and a restructuring in the construction sector (Elshakour et al, 2013). In light of the fact that there are new ways to measure performance, namely; Performance evaluation and management at the company level, as opposed to the project level, KPIs has been used by executive to measure performance and address issues and the company level, however, as will be shown below, there are many different issues that need to be resolved at the project level.

In reference to construction project delays in Saudi Arabia Ibrahim (2013) identified the contributing factors to delays in public construction projects in the country from the point of view of the owner. The results of Ibrahim’s (2013) study found that the top contributors to project delay were poor communication and coordination between construction parties, poor site management, payment delay, poor labour productivity, rework and bid award for the lowest price. Numerous other factors that have affected construction projects have been identified which include finance factors, construction factors, cost estimating factors and environmental factors, (Bubshait and Al-Juwairah, 2002).

The very nature of Saudi Arabia itself in terms of geography has an impact on construction projects in the country. The issue of remoteness can have an effect on construction projects where there is a loss of control over communications and management (Sidawi, 2012). This problem has blamed on plentiful reasons, which include poor management skills, infrastructure and human resources. Therefore, systematic project management challenges have an adverse effect on project processes and overall performance. Sidawi (2012) suggests that although many of these challenges can be mitigated through the employment of Advanced Computer based Management Systems (ACMS) that would help to improve overall management practices in accordance with international standard. There is still the need to overcome organizational problems such as poor resource management, information unavailability, ambiguous planning due to project complexity etc. which can be a hindrance to project management practices. For this to be achieved, Sidawi (2012) proposes that there needs to be an overhaul of the organisation's management system.

Despite the fact that the use of computerized systems being a proposed solution to the aforementioned problems, Sidawi and Alsudairi (2014) later suggest that there are a number of barriers to the utilisation of these systems in Saudi Arabia. The barriers include that traditional methods of communication are preferred in these projects and therefore dominate, and the preference for more traditional ways of management, both of which have been blamed for the lack of adoption of ACMS.

In reference to the many factors that can affect Saudi Arabian construction project management, Mitra and Tan (2012) say that it is can be an interaction amid the diverse features of a construction project; namely the interactions between the human, project methods and tools, supply chain management and financing. Specifically, although in construction projects in the largest is the Middle East. Saudi Arabia, have project participants that have both technical knowledge and experience in working on many different projects, often project managers do not have adequate experience for large international projects in the country. Another issue is that in these types of international projects in Saudi Arabia do not properly utilise the tools and formal methods such as technical memos and schedules, inspection records and reports which makes it difficult to gain a uniform interpretation and understanding of the project and its details. These problems are made worse by the fact that there are different contractors which have been given different aspects of the work in the same project, and therefore, without the use of formal methods it becomes difficult to pinpoint who is responsible for problems in a context that is very complex and fluid (Mitra and Tan, 2012).

It is the focus of this research to manage these wait time waste or delay in the planning and control processes of construction projects, thereby improving the delivery process of construction projects in Saudi Arabia.

2.4 Delay in Construction Projects

Delay is a common problem in construction projects. It is also a popular research subject. This is perhaps because the construction industry plays a significantly important role in the socio-economic development of nations. Saudi Arabia isn't different. In fact, the construction industry is at the very centre of the country's unprecedented economic development strategy which entails some of the world's largest infrastructure projects such as the construction of a state-of-the-art city (NEOM) with a budget of £400 billion (Michaelson, 2020). The industry is the backbone of the country's "2030 vision" and without which economic growth can't ever be sustained. Saudi Arabia has, for many years, invested billions of pounds in infrastructure projects, particularly on transport initiatives such as new roads, ports and bridges (Abdalla, et al., 2002). However, not many of these initiatives have been completed in time or on budget. In fact, delays and cost overruns are so common in the country that they have become seen as the norm and as a reality that project managers should just accept (Abdelhamid, et al. 2005). Unplanned delays can be very costly and cost plays a significantly important role in defining a firm's management effectiveness, operational efficiency and ultimately profitability.

There are various management issues that cause delays such as changes in design, specifications or materials (Ahmed, et al. 2002). The issues can so seriously that they involve alterations or changes to the original agreements between focal companies and their contractors. When this happens, it affects both clients' and contractors' abilities to stay on schedule and to avoid cost overruns. Under such circumstances, delays become inevitable (Alaghbari, et al. 2007).

However, although delays in construction projects are common in almost all countries (Alsuliman, 2019), it is more widespread in some countries than others. For example, in Saudi Arabia, it has been reported that about 10-30% of construction projects are completed on time and that delay-related cost overruns are becoming increasingly substantial (Alzara et al., 2016). Aibinu and Odeyinka (2006) studied the impact of delays on construction projects' delivery in Nigeria and found that the problem was widespread and that both clients and contractors share the blame for it. They claim that clients' failure to make fast decisions and contractors' inefficient utilisation of resources contribute to delays. Adamu and Hamid (2012) also studied delay in the context of Nigeria and found that this problem was so widespread that firms no longer worry about it. They advocated the adoption of Lean construction as a means of reducing delays and improving quality.

2.4.1 Causes of Delay in Construction Projects

There are a wide variety of factors that contribute to delays in construction projects. Although researchers have studied these factors extensively (e.g. Hamzah et al. 2011), their studies tend to have geographic boundaries or limitations which restrict their applicability to industries or countries with different operational or management contexts (Azhar et al., 2008). However, there are a few scholars who claim that several causes of delay are common across different geographical boundaries (e.g. Al-Tami, 2015), despite differences in significance and impact. Alrashed et al. (2014) conceptualised delay as a "risk" and examined its impact on the Saudi construction firms' performance. They found that the delay is often attributed to design failures, defective equipments/machineries, engineering challenges, contractor inefficiencies, labour mismanagement, material procurement problems, owners' indecisiveness, etc.

The causes of delays in construction projects can be divided into categories. Each delay can impact owners, government agencies, consultants and contractors in indirect and direct ways. Below, the table describes a selection of causes of delays in construction projects, as well as their subsequent effects.

Cause of Delay	Effects of Delay
o Financial delays such as contractor payments o Resource-related delays such as labour and productivity o Technical delays such as changes to methods and design o Economic delay resulting from changes to finances or equities o Environmental delays such as ground conditions or weather o Operational delays resulting from quality checks or bureaucratic interference o Political and government delay resulting from political change o Delays caused by relationship issues such as communication failures o Security: delays caused by injury or accident o Legal delays caused by changes to laws or terms	o Overrun in time o Legal involvement o Abandonment of the project o Arbitration o Contractors being introduced to assess and revise finances o Exceeding the budget o Projects which do not perform o Termination of contracts o Difficulty in payments being made o Failure of continuity on part of client

Table 2: 1 - Delays to Construction Projects: Their Causes and Effects

Source: Ogunlana and Promkuntong, (1996); Sadi et al. (2006)

A study was conducted in the Gulf nations of UAE and the Kingdom of Saudi Arabia, in which contractors ranked the causes to delays in projects. This is shown below:

Causes of delays	Rank as per contractors' perspective		
	UAE	KSA	Lebanon
Inadequate early planning of the project	1	16	11
Preparation and approval of drawings	2	1	3
Poor supervision and poor site management	3	16	11
Slowness of the owner's decision-making process	4	5	1
Shortage of materials on site	5	10	19
Conflict between contractor and the consultant	6	13	11
Obtaining permit/approval from the municipality/different government authorities	7	49	4
Lack of communication and coordination between the parties involved in construction (contractor–subcontractor–consultant–owner)	7	23	11
Productivity of manpower	8	55	27
Shortage of manpower	8	28	59
Incomplete drawings/specifications/documents	9	18	
Unsuitable leadership style of construction/project manager	9	36	17
Non-availability of materials on time	10	7	20

Table 2: 2 - Delays as Ranked by Contractors
Source: Ogunlana and Promkuntong, (1996); Sadi et al. (2006)

This table indicates the importance of synchronising correlation between delay causes in these countries in order to assess the relative import of each cause in the area. For example, only three of the causes of delay ranked in the top ten in KSA were agreed to be important in the UAE according to contractors. The table also shows that the top three causes in Saudi Arabia related to unavailability of material, approval and preparation, and owners' decision-making delays.

Causes of delays	Rank as per consultants' perspective		
	UAE	KSA	Lebanon
Preparation and approval of drawings	1	11	1
Slowness of the owner's decision-making process	2	2	9
Financing by contractor during construction	3	2	26
Shortage of manpower	4	27	54
Inadequate early planning of the project	4	16	9
Skill of manpower	5	27	9
Non-availability of materials on time	6	16	6
Productivity of manpower	7	49	32
Poor supervision and poor site management	8	11	20
Obtaining permit/approval from the municipality/different government authorities	9	21	47
Unsuitable leadership style of construction/project manager	10	24	2
Delays in contractor's progress payment (of completed work) by owner	10	5	20

Table 2: 3 - Delay Causes According to Consultants
Source: Ogunlana and Promkuntong, (1996); Sadi et al. (2006)

The table indicates that consultants in KSA blamed the shortage of workforce and skills as well as lack of leadership for delays. In Lebanon, lack of workforce was also noted as a cause of delay, alongside difficulty in acquiring approval. In the UAE, however, there has been less significant delay as a result of consultants' behaviour.

Moreover, the most common causes of delay in construction projects can be divided into four broad groups; namely, consultant, contractor, client and external factors.

- **Consultant-related Factors**

Consultants contribute to construction delays as much as other parties. Avenue and Odeyinka (2006) explained that the consultants' failures to communicate effectively with project owners, to provide complete architectural drawings in a timely manner, and to take an active role in the actualisation of their plans could lead to unnecessary delays. Shahsavand et al. (2018) have also found that consultants' underperformance leads to unanticipated delays. The amount of wasted time depends on how far down a project's life cycle construction has progressed and how severe the disruption is to a project's critical path (Al-Khalil and Al-Ghafly, 1999). Also, Al-Kharashi and Skitmore (2009) claimed that consultants' lack of experience, lack of time to thoroughly review all relevant design documents, and significant design alterations contribute to project delays. Their claim reminds one of the differences between unnecessary delays and the time spent on solving or fixing unforeseen issues. The earlier is a form of waste which should be reduced, whereas the latter is a manageable risk which should always be accounted for in the planning and development (pre-construction) phase (Ahrens, 2006). According to Assaf and Al-Hejji (2006), the most significant consultant-related cause of delay is "change order" which requires multiple stakeholders to work closely together to produce a practical design solution to a given problem. Shahsavand et al. (2018) also claimed that over "70 percent of the projects experienced time overruns" due to unscheduled 'change orders'. It also found that consultants' inflexibility, poor communication, lacklustre performance, lack of experience and personal conflicts with engineers contributed to project delays.

Moreover, Oyegoke and Al-Kiyumi (2017) investigated the causes of delay in megaprojects and discovered that several consultants-related factors contributed to unnecessary delay. Their analyses showed that communication breakdown between clients and consultants and design errors were major causes of delay. They also found that changes in specifications and design alterations contributed notably to delays in construction projects. Alrashed, et al. (2014) also attributed the delays to design errors, alterations in specifications and sudden design changes. In addition, pro-quality activities such as risk assessments, design inspections and design, testing have also been found to contribute to scheduling overruns.

- **Contractor-related Factors**

Contractors' management practices have a significant impact on construction projects' delays. Alrashed et al. (2014) studied risks in construction projects in Saudi Arabia and found that contractors' management failures and inabilities to efficiently deploy their resources were key contributors to unnecessary delays. Aibinu and Odeyinka (2006) investigated the causes of construction delay in Nigeria and identified several contractor-related factors which included: lack of equipment, frequent machineries breakdown, inefficient procurement operations of construction materials, ineffective planning and scheduling, inefficient resources deployment, and financial constraints. Vilventhan and Kalidindi (2016) also highlighted several causes of delay to which construction contractors were major contributors; namely, inefficient material procurement operations, financial constraints, changes in material prices, operational conflict between contractors and sub-contractors, ineffective management of the human and physical resources, health and safety issues and poor schedule management.

- **Client-related Factors**

Projects' owners also contribute to construction delays. In fact, in some instances, are far more impactful than other stakeholders. Sweis et al. (2008), in their study of causes of delays in Jordanian construction projects, found that project owners' sudden demands and frequent change orders contributed greatly to unplanned delays. Another study by Arantes et al. (2015) outlined several factors which the authors believed to cause delays. They included: cash flow problems and payment delays; slow decision-making processes; mismanagement of materials procurement operations; lack of incentives (e.g. performance related pay); interferences at the operational level; conflict of interest; leadership disruptions; and political interventions.

- **External Factors**

There are numerous factors which are beyond the control of a project's stakeholders and that can have a detrimental impact on the contractors' abilities to stay on track and to finish projects on time. Natural disastrous, for instance, are often unavoidable and difficult to manage. In Saudi Arabia, severe weather conditions such as excessive day-time temperatures are typical problems that construction firms have to deal with. In fact, the Saudi government introduced a directive prohibiting working under the sun between 12:00 and 15:00 (Taha, 2017). Other external causes of delay include: restrictive laws and regulations; social unrest; legal disputes; major/fatal accidents; construction permit/approval delays, hyperinflation; labour strike; bad political climate; and socio-cultural changes (Arditi and Pattanakitchamroon, 2006).

2.4.2 Types of Delays

There are different types of delays that have been reported and discussed in the literature. Also, different scholars have classified certain types of delays differently. However, delays in the construction industry are typically interdependent and tend to have similar characteristics (Shahsavand et al., 2018). Al-Ghafly (1995) divided delays into four main categories; namely excusable delays, compensable delays, non-excusable delays, and non-compensable delays. Other researchers have classified delays under other banners such as critical delays and non-critical delays; and concurrent delays and non-concurrent delays.

- **Excusable Delays vs. Non-excusable Delays**

Excusable delays are typically beyond the control of contractors such as labour strikes, poor weather conditions and design/specification changes. All acts of God such as floods, fires, virus breakouts and other natural disasters are classified as excusable delays. It's common for project owners and contractors to agree on a clear definition of delay prior to the start of any construction work. Such agreement is often incorporated into construction agreements in the form of legal clauses so that all parties are aware of their responsibilities in terms of taking all relevant steps to eliminate, prevent, or at least reduce the risk of delay (Amoatey et al. 2015). Construction agreements should always provide details on different types of delays and the legal and financial consequences of each type of delay. Agreements should also clarify how long 'extension time' contractors may have for different kinds of excusable delays.

Non-excusable delays are concerned with what's within the control of contractors and delays that can be avoided through effective management of time and resources like slow progress, accidents and machinery breakdowns. Assaf and Al-Hejji (2006) asserted that non-excusable delays express contractors' failures to maintain good operational performance. They argued that the contractor's inability to meet deadlines; to stick to design specifications; to ensure high work quality; to display good workmanship; to prevent avoidable labour strikes; and to maintain industrial best practices were non-excusable and should be confronted by project owners.

- **Compensable Delays vs. Non- compensable Delays**

Compensable delays are those delays in which contractors are entitled to compensation. They are often caused by parties other than the contractor such as the project owners or consultants. In such situations, contractors become entitled to receive compensation to cover any expenses that may have been incurred as a result of project extension (Arditi and Pattanakitchamroon, 2006). In contrast, non-compensable delays are concerned with situations in contractors aren't entitled to any form of compensation, perhaps because the delays are non-excusable or due to the fact that the contractors themselves are responsible for the delay (Assaf, 1995). Azhar et al. (2008) explained that construction contracts or agreements should clearly define what kind of delays that is compensable and which isn't. However, it is a common practice for project owners to grant contractors extra time to finish off the project without any additional funding if the delay is non-compensable or if it is caused by the contractors (Chidambaram, 2012).

- **Critical Delays vs. Non-critical Delays**

Critical delays are situations or circumstances which hinder contractors' abilities to finish a project in time. They undermine the overall project schedule and make it quite difficult for contractors to stay on schedule and to complete projects on time. Alhajri and Alshibani (2018) explained that critical delays are typically identified or predicted using Critical Path Method (CPM) which helps project managers to develop adequate plans to deal with circumstances that disrupt critical construction activities. All kinds of projects have critical activities that have to be considered when developing time schedules and whose delay will have a direct impact on the overall timeline of the projects (Al-Kharashi and Skitmore, 2009). CPM is commonly used to identify these activities and to devise appropriate contingency plans to deal with any unforeseen circumstances. The CPM has the following objectives:

- To estimate the date by which projects should be completed.
- To identify the activities that have the greatest impact on a project's timeline.
- To evaluate the extent to which each project activity can deviate from its original timeline without having a detrimental impact on the overall project schedule.

There are two main methods which are used to estimate a project's completion date using CPM; namely, forward-pass estimations and backward-pass estimations (Alkharmany 2017). The forward-pass method estimates the earliest possible start date of a project and the earliest finish date, whereas the backward-pass method calculates the latest start date and latest completion date (Alsuliman, 2019). Al-Ghafly (1995) stated that identification of which activities have the greatest impact on project completion dates depends heavily on a number of important factors; namely:

- The nature of the project in terms of size, complexity, etc.
- The contract's requirements, especially in terms of construction sequence and stages
- The complexity of the project umbrella plan and schedule.
- The physical constraints of the project.

It is important to note that no matter how thoroughly project managers plan for project execution and completion, there will always be factors or variables that haven't been considered and which cause unnecessary delays later on (Al-Tami, 2015). In other words, there is just so much project managers can do to prevent delays. Delays will always occur no matter how well a project's plans are (Ghafly, 1995). Ambituuni (2011) argued that one shouldn't worry too much about non-critical delays and about incidents that don't have a significant impact on a project's time schedule and its completion date. They also clarified that critical delays aren't always the result of non-excusable delays, but they can also be the result of excusable delays.

- **Concurrent Delays vs. Non-concurrent Delays**

There are various definitions of concurrent delays. Their definition depends on the nature of a project. However, it is generally understood as two independent incidents or activities happening at the same time and both having an impact on a project's schedule, one event may be caused by the focal company while the second event is caused by a sub-contractor. Elawi et al. (2015) explained that concurrent delays, refer to two or more types of delays that happen at the same time and have a notable impact on a project's completion date. It is also argued by Ogunlana and Promkuntong (1996) that concurrent delays don't necessarily have to be interdependent or occur at the exact same time. Instead, concurrent delays, refer to obstructive events whose impact on a project's schedule occurs concurrently. This often happens when two or more stakeholders (e.g. Project owner and contractor) do things or make decisions that lead to activities being put on hold (Sambasivan and Soon, 2007). In contrast, non-concurrent delays, refer to events or incidents that cause delays, but their impact or effect on a project's timeline doesn't occur at the exact same time.

Concurrent delays may be excusable and could even carry compensations for contractors and sub-contractors. The compensation doesn't have to be financed. It can be in the forms of time extensions, relief funds/grants and remission of liquidated damages, but they all depend on the terms of the construction agreement/contract (Mahamid, 2013). Delays that aren't excusable, but occur at the same time as events/incidents caused by project owners aren't always eligible for compensation and could even carry penalties, especially if their impact on a project's completion date is so severe (Mitra, et al. 2012). On the other hand, contractors and sub-contractors can't and shouldn't be penalised for delays caused by the project owners, consultants or any other independent stakeholders.

2.4.3 Impact of Delays

It is impossible to overemphasise the impact that can be caused to contractors, clients and owners by delays to construction projects (Elawi, et al. 2015). The actual degree of impact can vary, depending upon the type and size of the construction project, the environment within which it is being conducted, and the principles of government in the area where it is taking place. Global research on the question suggests that delays to construction correlate directly with budget overrun, with the outcome being that projected dates for the delivery of many projects are not, or are barely, met (Ball, 2019).

When a project results in costs that are in addition to those agreed in the budget, and when a contractor agrees to accept these costs, this is known as overrun (Chauhan, Shah and Venkata, 2008). When cost overruns resulting from delays are accepted, however, it results in a monetary loss for consultant, contractor and indeed sometimes a commissioning government, which can have detrimental effects on consultants' reputations (El-Razek, et al. 2008). At the same time, the construction-related industry can suffer from significant projects, particularly those intended to help develop areas socio-economically, being abandoned (Sweis, 2008). Where delays to projects result in their ultimate abandonment, this negatively impacts construction workers, while also having an effect on governments, causing them to lose revenue and potential future investment because the image of both government and company has been negatively affected. This can result in diminished foreign investment (Kaliba et al. 2009).

2.4.4 Construction Project Delays in Different Countries

While delays to construction worldwide pose similar issues to all construction workers and consultants, each country notes slightly different causes, depending on project size, type of contract and terms.

S/N	Countries	Causes of Delays	References
1	Kuwait	Covering 27 urban district with 450 project owners and developers identified 3 key causes of delay factors to be: financial constraints, numbers of change orders, and lack of experience by owners.	Jarkas, et al. 2012.
2	Nigeria	According to Odeyinka and Yusif (1997) seven out of ten construction projects face delays, the causes were inclement weather, shortages financial resources and improper contract management.	Aibinu and Odeyinka (2006)
3	Malaysia	A study conducted in 2005, disclosed that about 17.3% of the construction projects are experiencing and are likely to continue experiencing delays of up to 3 months. The factors responsible for delays in Malaysia include lack of technical knowhow of contractors, lack of contract terms experience, poor financial management by the client, sub-contractors, labour, material and suppliers, poor communication between contractors and clients, stakeholder engagement and construction errors.	(Sambasivan and Soon (2007)
4	United State of America	A study conducted in California, in a form of grouped categories into three; cause within the consultant's control, Cause within owner control and causes beyond both consultant and owner's control. One of the studies conducted in Florida also revealed that most construction project delays are associated with owners and consultants. Where the primary delays are traced to lack of monitoring mechanism, poor project design flows and lack of compliance with building codes and practices regulations.	Ogunlana and Promkuntong (1996)
5	United Kingdom	According to the National Audit Office in the UK, about 70% of the construction projects executed in the UK experience delays. Supported by the UK building Construction Services, about 40% of the construction projects investigated experienced delays and failed to meet the original planned completion date according to contract. The most anticipated sources of delays in the UK include completion sequence by the client, contractor's	Olawale and Sun (2015); Parry (2015); Agyekum-Mensah and Knight (2017).

		schedules, client and owner's priorities, construction types, project's complexities, design defects, timelines of projects and project location.	
6	Australia	A study conducted in Western Australia within 32 construction professionals identified 48 possible causes of delays in construction projects. With the result, the most predominant reasons to why delays occurs in construction are associated with lack of proper skills, unrealistic deadlines for project completion, Unexpected delays such as weather condition, financial difficulties and inadequate labour.	Hsu, Aurisicchio, and Angeloudis (2017); LINDSAY (2017); Matin (2016).
7	Pakistan	The delays in Pakistan are associated with high cost of materials, poor projects management, hight cost of machineries, instability in the prices of working materials, unbalanced price of industrial supplies and lowest bidding procurement method.	Azhar, Farooqui, & Ahmed (2008)
8	Jordan	The cost of construction delays in Jordan is not far distinctive from other countries in the Gulf region: Financial difficulties, poor planning, lack of proper scheduling, severe weather condition, lack of adequate labour and lack of consistency with changes in material orders.	Sweis, Sweis, Hammad, & Shboul (2008).
9	Zambia	Zambia's construction sector is not an exception to the effect and impact of construction delays. The include payment of contractor's delays, process of finances for contract, contract modification and economic problems.	Kaliba, Muya, & Mumba (2009); Muya, et al. (2013)
10	Kingdom of Saudi Arabia (KSA)	The construction sector in the Kingdom of KSA is regarded as one of the economic indicators for generating revenue behind the Oil and Gas industry in the Kingdom. The industry contributes immensely to the overall development of socio-economic activities. Even though, status of delays in the construction projects and the impact in the kingdom cannot be over emphasised. A study carried out by Albogamy et al. (2013) in KSA and Jordan, revealed the five (5) key causes of delays in construction projects were related to; delays by sub-contractor's work, lack of technical knowledge, poor planning/design, low performance in the bidder system and inability to keep paying as the project progressed. Researchers are of opinion that more than 70% of the projects undertaken in the kingdom experiences delays. In another study by Water and Sewage Authority in the Eastern Province of the	Albogamy et al. (2013) Zain Al-Abidien (1983) Al-Sultan (1987) Falqi (2004) Al-Kharashi and Skitmore (2009) Faridi and ElSayegh, (2006) (Frimpong et al (2003) Al-Najjar (2008) Koushki et al (2005) Asnaashari et al (2009)

		Kingdom concluded that 45 projects (59%) of the 76 projects completed experienced delays. In another study conducted by Falqi in 2004, 952 projects (40%) out of the 2379 projects in the Kingdoms have had delays with slide development to previous studies. However, the reasons why delays are highly experienced in the Kingdom's construction industry are associated with the followings: poor planning, lack of proper scheduling, lack of experienced frontiers in projects and labour, conflicts between stakeholders, types of tendering for contract projects, delays in progress payment for a work-in-progress, Bureaucracy and conflict among government agencies, scope of work alteration and design and lack of transparent communication due to language barriers. The aforementioned factors cause delays in the construction industry not only in the KSA but across the Middle East.	Mahamid et al (2012) Odeh and Battaineh, (2002) Alghbari et al (2007) Al-Momani (2000).

Table 2: 4 - Views on Construction Delay across Selected Nations

Source: Aibinu and Odeyinka (2006); Kaliba, et al. (2009); Muya, et al. (2013)

As Table 2:4 indicates, there are evidently many causes of delay that are common across all projects, but the causes may also differ according to location, the size of the project, other factors including the experience levels of the stakeholders involved. However, the issues of overrunning in terms of both cost and time seem to be the primary concerns of the construction industry in Saudi Arabia. In a country where this industry contributes a quarter of the national economic growth, this is a significant concern causing considerable impact upon the country's economy (Gardezi, et al. 2014)

Over the past twenty-five years, a huge increase in the number of projects being carried out in KSA has been observed (Haadir and Panuwatwanich, 2011). Accordingly, most of these projects have dealt with difficulties relating to overrun in time and cost, which has in turn generated a high level of wastage (Haadir and Panuwatwanich, 2011). The so called "Lean" method of construction has been introduced and adopted by many companies across the industry to address these concerns (Mitra and Wee Kwan Tan, 2012). Implementation, however, has been sporadic and often uncoordinated and ineffective, meaning that further exploration is needed (Sadi, Assaf, Sadiq Al-Hejji, 2006).

2.5 Project Management

Although, Project management has been defined severally by many scholars, the definition of the subject cannot be completed or understood without recognising the two major components "Project and Management". Lester (2013) describes a project as a unique set of coordinated activities, with definite starting and finishing points, undertaken by an individual or organisation to meet specific objectives within defined schedule, cost and performance parameters. Nwachuku and Fidelis (2011) define management as planning, controlling, directing, and coordinating of individual, group or organisational goal and objectives with the ultimate aim of achieving maximum benefit.

The project management literature offers many definitions, the most straightforward of which is proposed by PMI (2016). These and other definitions are presented in Table 2:5, where the most common approach is to consider project management as the application of necessary skills, tools, knowledge, approach and techniques to project activities to meet the project requirements. This definition is adopted in the present study. Clearly, it mirrors the functions of project management, which are to coordinate, plan, and control the overall project via the application of knowledge, skills, tools and techniques to a broad range of activities, in order to meet the requirements of the clients. The definition implies that planning, coordination and control, constitute the backbone of project management.

Source	Definition
Lock (2013)	"…the management discipline that plans, organise and controls people, money and cash so that projects are completed successfully in spite of all the risk".
PMBoK (2004)	"..the application of knowledge, skills, tools, and techniques to project activities in order to meet stakeholder's needs and expectations of a project".
Lester (2013)	"..the planning, monitoring, and control of all aspects of a project and the motivation of all those involved in it, in order to achieve the project objectives within agreed criteria of time, cost, and performance".
Abbasi and Al-Mharmah (2000)	"...a relatively modern practice that attempts to achieve planned objectives within specific time and cost limits through optimum use of resources, using an integrated planning and control system".
Chitkara (2000)	"…the art and science of mobilising and managing people, materials, equipment and money to complete the assigned project work on time with budgeted costs and specified technical performance standards".

Table 2: 5 - Definition of Project Management

Project management is a contemporary practice that endeavours to achieve set objectives within a specific period of time and within a limited budget through optimum use of available resources using a unified preparation and monitor structure. Projects such as houses, roads, factories, irrigation works, dams, schools, hospitals and others are the physical foundations on which development efforts and improved living standards are established. The development and recognition of project management is inevitably continuing to increase as resources become scarce. The application of project management concepts and techniques is crucial tool for planning, organising, managing and control of work, which leads to better performance and increased productivity.

2.6 Importance of Project Management

The PMBoK guide states that project management consists of ten major functions: integration, scope, time (planning, scheduling, and controlling the project), cost, quality, human resource, communications, risk, procurement and stakeholders (PMBoK, 2013). In any project environment, the definition of project success is that it should be delivered on time, within the allocated budget and to technical specifications and that it should deliver customer satisfaction. That is to say, time, cost and quality are the fundamental objectives of project management. Serpell et al (2015) argue that the key to successful construction projects is to manage the projects efficiently, that is to do the work on time, within budget and according to quality standards. These objectives of a project need to be clearly conveyed and reinforced by all participants at all stages of the project. Hence, to help in meeting them, particularly when a project is exposed to time, cost, and resource constraints, various project management processes can be used. Planning and control have perhaps the greatest potential to help in delivering a project efficiently, reducing construction time and cost while ensuring the desired quality.

2.7 Construction and Project Management

Construction is a project-based industry (Shirazi et al, 2007) and the characteristics of construction projects distinguish them from those in other businesses, as the processes involved are different from those of manufacturing and trading in many respects (Besner and Hobbs, 2008). Koskela (2000) groups the substantial individualities of construction projects into three main categories: the nature of the projects, site construction output and provisional organisation. According to Pierce (2013), there is still the idea that management procedures that are derived from project management are not necessary and it is enough to walk around a site in order to ascertain if a plan for a project is going to work or not. Pierce (2013) further reported that the construction industry had changed and thus required a new control and management approach for construction projects. Basically, as construction projects are becoming increasingly complex and the traditional methods of control are not as effective, construction firms need to consider the adoption of more advanced management practices (*See* Lalmi et al., 2021). Scholars like Lalmi et al., (2021) believe that the adoption of contemporary management systems such as agile management and Lean management will help construction firms to "promote change, boost interaction with the client and increase project value, by using the agile approach component to increase the probability of success of construction projects; to eliminate waste by embodying the lean approach component" (p. 921). Azanha et al. (2017) also investigated the relative advantages of agile project management and concluded that the use of agile project management tools and techniques such as Scrum would help project managers to achieve "75 percent reduction in development time, compared to traditional methods" (p. 121). They explained that the improvements were the result of "increased motivation and staff satisfaction, better control of requirements and especially higher quality of the delivered system, generating added value to the organization". However, despite the many benefits of contemporary project management systems (e.g. Lean project management) and the limitations of traditional project management methodologies, many project managers, especially in Saudi Arabia, still use many of traditional tools and techniques. Ahimbisibwe et al. (2015) claimed that although "no more than 20 per cent of all projects have the characteristics of traditional projects, research shows project managers continue to apply these traditional methods to projects for which they are not suited" (p. 7). Ahimbisibwe et al. (2017, p. 400) also compared the traditional plan-based and contemporary project management methodologies and found that the complex and dynamic natures of today's projects necessitate the switch from linear lifecycles to iterative or adaptive life cycles. They argued that traditional one-time planning tasks should be "replaced by an iterative and adaptive series of just-in-time tasks each of which is executed only when needed. This provides flexibility and adaptability to the project, enabling it to cope more readily with change requests". With these arguments in mind, this research set out to explore how the use of contemporary management practices could help Saudi construction firms address the issues of delays and cost overruns and optimise their operational efficiency. More specifically, this research explored whether the transfer of Lean Management's principles, tools and techniques in the construction industry would boost the effectiveness of current project management practices and help construction firms mitigate the risks of delays and cost overruns which are widespread in the Saudi construction industry.

2.7.1 Definition of Project Management in Construction

Construction project management inherits its vital importance from the strengthening of general management definitions described earlier. The CIOB (2011) defines construction project management as "the overall planning, co-ordination and control of a project from inception to completion aimed at meeting a client's requirements in order to produce a functionally and financially viable project that will be completed on time within authorized cost and to the required quality standards". Walker (2002) provides a more comprehensive definition of construction project management as the planning, control and co-ordination of a project from the beginning of the project to completion. The project deliverables must conform to client's requirements especially in terms of quality, utility, cost, function, time and the creation of relationships between other elements. Therefore, the purpose of project management is to ensure that project deliverables are in line with the client's requirements. However, meeting or exceeding clients' needs and expectations invariably requires balancing competing demands among:

1. Scope, time, cost and quality
2. Stakeholders with differing needs and expectations
3. Identified requirements (needs) and unidentified requirements (expectations).

2.7.2 Characteristics of Project Management in the Construction Sector

According to Chao et al. (2009) features of a construction project include the scale of a project, the type of project, the level of construction complexity, and in more reference to the characteristics of the project participants; the capability for construction management, experience, communication and design changes. Nicholas and Steyn (2008) report that some of the key features of project management in the construction sector include:

1. The project manager heads the project and roles autonomously of the chain of subordinates. The project is structured and organised to have an orientation meant to achieve a set of goals with the support of teamwork.
2. The project manager is the person who is saddled with responsibility beyond effort to meet the project objectives set by the client or owners of the project.

3. In order to accomplish a full project's success, the project management team must integrate specialised sourcing to handle all the functions within and outside the contractor's teams.
4. The project manager is responsible for integrating people from different functional areas or subcontractors and specialist who work on the project.
5. The project manager liaises directly with other duty managers who might be responsible for the individual duties and personnel within the project.
6. While project manager is keen on delivering a skew and tight schedules from beginning to end, whilst functional managers are responsible for ensuring the project specification is maintained, resources are pulled and used judiciously and timing for progress in adhering to support the organisational goal. Even though, conflict may arise between project and duty managers over the time and talent to be allotted to a project.
7. Decision making, accountability, outcomes and reward are shared between project team and supporting functional units for the overall success of the project.
8. Although the project organisation is a temporary setting for a short period, the subcontracting unit from which it is formed is permanent. When the project ends, the project organisation is unbundled, and people return to their subcontracting unit.
9. Project management groups into on-going jobs in various supporting functions such as supplies, human resources and many more for the purpose of completing a project.

2.7.2.1 Scheduling in Construction Project

In project management, it is essential to have project schedule records which are estimates for an actual start date to finish date and the duration period of each work forecast (Turner, 2014). Furthermore, Turner (2014) argued that complicated schedules, record up to five types of each of the start date, finish date, duration, and float: the early, late baseline, schedule and actual dates, with variances which might occur during the project period.

The Duration: Duration is the actual time estimated for the entire project to be completed.

Early and Late Dates: These dates are forecast estimate duration of all activities during the cost of a project circle. The start of one activity may be dependent waiting for other work finishing. Thus, there is an earlier date by which an activity may start which is known as *an* *early start date*. The earliest start date plus the estimated duration is the *early finish date,* the earliest date by which the work can finish is guaranteed by the two. Accordingly, other work may be dependent on the activity being finished, meaning the activity cannot be carried out without the completion of the other. So, there is a later date by which it can be finished and not delay completion of the project, which is referred as the *late finish date.*

Float: The float is a flexible opportunity where work element can start between the late start date and the early start date.

Float = Late start date – Early start date

Planned, Baseline and Schedule dates: *Planned dates* are dates between the early estimated date and late finished dates when the work is pre-determined to be carried out. The original contract proposal for the project is referred to as the *baseline date*, and the current plan that is changing as the *schedule date*.

Turner (2014), further emphasized that there are up to fifteen dates and times related to a work element as stipulated in Table 2.2. The process of scheduling the project is the assignment of values to these dates and times.

2.7.2.2 Tools and Techniques in Construction Project Management

There are various tools and techniques which construction project managers can employ to monitor, control and manage the different phases of construction. One of these tools is work breakdown structure or WBS. Projects often fail because important parts of the project are often forgotten and therefore, it is important not only to identify tasks but also to break them down. The function of a WBS is to help in determining how long tasks will take and how much they cost by breaking those tasks down into individual tasks, using a WBS tasks are broken into smaller tasks until they cannot be subdivided any further, in it also important to remember that the sequence of tasks is something that is not considered in a WBS (Lewis, 2007). Although the WBS is popular among project managers and has many benefits, it is not without weaknesses or shortcomings. Firstly, WBS oversimplifies project tasks and activities. It can be quite deceiving as it fails to highlight the interdependencies between different tasks and how interconnected activities affect each others' completion schedules. It also fails to highlight the tasks which are most critical for project schedules. Secondly, the WBS technique is more concerned about the identification of relevant tasks and the establishment of different task categories than about the development of the right level of detail, particularly in terms of how key tasks affect and are affected by other tasks. Thirdly, construction projects tend to be fast-moving and dynamic, so the WBS developed in the early stages of a project can become outdated and irrelevant rather quickly. It is well known that construction project schedules and activities change all the time, so unless the WBS is constantly updated, its value will diminish very quickly as projects progress from planning to construction and completion.

Moreover, Love and Irani (2003) developed a Project Management, Quality, Cost System (PROMQACS) to help project managers better manage construction projects' costs. This system does not only determine costs, but it also determines the root causes of rework. It enables construction project managers to identify the shortcomings in project activities, allowing them to take remedial action (Love and Irani, 2003). It also enables clients and contractors to evaluate their performances in addition to determining the factors that are responsible for rework, moreover. Thus, this system can be applied to track changes in the client's requirements which in turn enable the construction project managers to establish instruments for modification control for rework activities (Love and Irani 2003). However, although the PROMQACS offers construction project managers with numerous benefits, especially in relation to cost management, it has some limitations. Firstly, it is inconsistent with this research's need because it focuses solely on the subject of cost management and on the issue of rework and fails to account for how inexcusable and unnecessary delays affect the overall cost of construction projects. Secondly, it is quality-oriented so it is more suitable for quality management than in solving the problems of delays and cost overruns. Thirdly, it consumes a lot of time and effort, particularly in terms of data input which is not ideal for project managers who need to make swift decisions. Fourthly, it requires input from various stakeholders in order to build a clear picture of which areas need improving. This is an issue because not all stakeholders are willing to openly and share information about their areas of underperformance with other stakeholders or organisation.

Furthermore, Patterson and Ledbetter (1989) also developed a quality performance management system (QPMS) which was designed to help managers with quality issues in construction projects. This system is based on the idea that rework accounted for 12.5 percent of the project total cost and that project quality accounted for 25 percent of project cost and there was a link made the quality cost and the cause of the problem, however, although this system was considered to be flexible as well as simple, it did not consider the effects that these quality failures have on time related costs and was not good enough in determining the actual causes of the failure (Love and Irani, 2003). A new version of the QPMS was the quality performance tracking system (QPTS) which was designed for determining the associated costs of quality for quantitative analysis purposes as well as being designed for tracking deviations (Love and Irani, 2003). Using this system deviation costs are associated with rework, liability, warranty and impact, and in order to track failures it became important to ask a couple of questions such as which sub contract, who was affected and what were the associated costs, how was it detected and what was the cause? (Love and Irani, 2003). Unfortunately, neither QPMS nor QPTS are consistent with this research's purpose and needs. The two systems focus more on quality management in construction projects than on the problems of delays and cost overruns.

Last but not least, Song et al. (2006) developed a system that helps project managers electronically track the movement of construction materials throughout the supply chain using radio frequency identification or RFID. Song et al (2006) introduced this technique to facilitate automatic and electronic tracking of materials in construction projects using radio frequency systems. Because materials account for around 50 to 60 percent of the total cost of a construction project the handling of materials has a direct effect on the project’s overall performance because it helps to manage the movement of materials because it provides positional accuracy (Song et al., 2006). This system is also inconsistent with this research's need despite the fact that the use of the RFID technologies could help Saudi construction firms to better integrate and streamline their supply chain operations. This research focuses specifically on the use of Lean's tools and techniques to solve the problems of delays and cost overruns in the Saudi construction industry.

In summary, there are numerous construction project management tools and techniques which project managers can use to manage the different phases and aspects of construction projects, but frameworks which advocate and facilitate the adoption and use of Lean tools and techniques are rare. Almost all of the frameworks, models and systems identified from the construction project management literature are either inconsistent with the needs and purpose of this research; or focus on issues other than delays and cost overruns.

2.8 Issues in the Construction Project Management

Researchers argue that project management in construction is based on deficient theories (Ballard and Howell, 1998; Ballard, 2000; Koskela and Howell, 2002). Koskela and Howell (2002) cite the simplicity and insufficiency of two underlying theories, `management as planned' and the `thermostat model' of control, whose shortcomings they summarise under three headings:

1. The unrealistic role of planning and poor short-term planning;
2. Unsystematic management of execution and
3. A narrow view of control as measuring and taking corrective action, rather than as a process of learning.

The researchers further argued that recent construction project delivery practices flopped down to stipulate a reasonable basis for improvement and also inadequate when projects are complicated, ambiguous and quick. The conventional construction planning and control system, as described in the PMBOK guide (2004), has been criticised for the inadequacy of its fundamental theories and the ineffectiveness of its tools and techniques (Koskela and Howell, 2002; Howell and Koskela, 2004). Two major criticisms are discussed in the next section of the traditional theory of project management.

2.8.1 Project Management Theory is based on the Management-as-Planning

The PMBOK Guide (2004) categorised project management into initiating, planning, executing, controlling and completing or closing process. Koskela and Howell (2001) demonstrate the developments process of planning, executing and controlling as establishing a locked circle (Figure 2:5): the planning processes provide plans, which are realised by the executing processes, while changes from the baseline for requests for modification, which lead to corrections in execution or changes in further plans. In other words, the emphasis is firmly on planning, while little guidance is provided for executing.

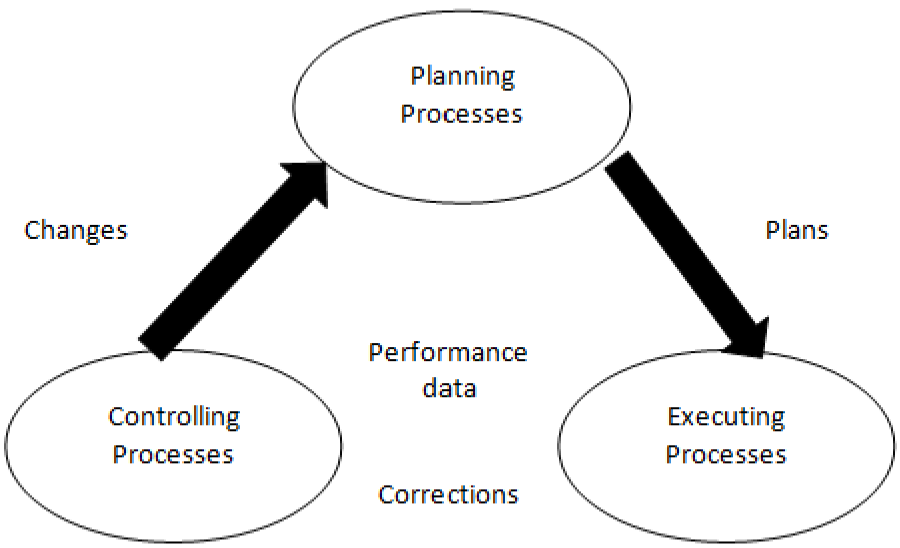

Figure 2: 5 - managerial process in project management

Source: Koskela and Howell (2001)

Koskela and Howell (2001) argued that the approach to project management described in the PMBoK guide is based on two fundamental philosophies: management-as-planning (for planning and execution) and the thermostat model (for control). Their report perceives the key deficiency of this method to be that it is inadequate from the perspective of project management realism and argued that the procedure undergoes from three shortcomings:

1. The role of planning is not logically defined, and short-term planning is normally carried out poorly or simply neglected.
2. Execution is not managed efficiently. In other words, action is taken for tasks to be pushed by the plan without considering the real conditions as higher-level plans are translated into short-term plans and then into action.
3. Control is too narrowly seen as measuring and taking corrective action, rather than as a process of learning.

These deficiencies affect the function of planning, which is conducted for other reasons, with the exception of the smooth running of the execution phase. There is a lack of transparency of information flow between planning and execution that could help anticipate an underlying challenge in execution earlier. The motive for planning is repeatedly controlled and comes from external resources: legal considerations and owners' obligations, slightly than from the construction procedure. Preparation develops more about explanation on what has occurred, rather than limitation elimination in finishing, thus there is almost total deterioration of the role of this function (Laufer & Tucker 1987): the role of planning is changed from introducing and directing action before it takes place (as suggested by theory) to influencing and regulating operations while in progress (as intended in practice) and to follow-up and status reporting (as realised in practice) (Koskela and Howell, 2002).

2.8.2 Project Management Theory is based on Transformation

Researchers have highlighted that construction is managed according to the transformation concept which management centres efforts on task management (dos Santos, 1999; Koskela, 2000; Koskela and Howell, 2002). However, task management is not implemented systematically across all phases, resulting in added variability. Task management is the process of managing a task (or task portfolio) through its lifecycle, including planning, testing, tracking and reporting. Task management can help individuals to achieve goals, or groups of individuals to collaborate and share knowledge for the accomplishment of collective goals (Koskela and Howell, 2002).

Even a situation where a plan is intended to execute systematic task management, it is corrupted by the highest ranked fundamental unpredictability, becoming disorganised. The result is poorly monitored (a low level and inefficient expectation of production) through all stages. Koskela and Howell (2002) critique production-based changes for its misguided belief that the inputs to a task and the resources to execute it are ready when it is authorised to start. According to Koskela (1999), the predetermined changes are advantageous in supporting new discoveries where more work is needed to be accomplished, thus, it is absolutely feasible to perceived projects based on this view. Although, the transformation thought is not necessarily helpful in deciding how not to use resources needlessly. Instead, the concepts of the flow view explain how the variability of production impacts on resource use.

Therefore, Koskela (2000) suggests three points of view: transformation (realising value-adding activities efficiently), flow (reducing the share of non-value-adding activities) and value (improving customer value). Table 2:6 shows the new theoretical foundation of project management, which considers transformation, seeing management as comprising planning, execution and control. The issues in construction project management will be addressed in this research by applying the Last Planner System (Ballard, 2000), which is a system for production planning and control in construction based on the Lean concepts.

Subject of theory		Relevant theory
Project		Transformation, flow, value generation
Management	Planning	Management-as-planning, Management-as-organising
	Execution	Classical communication theory, language/action perspective
	Control	Thermostat model, Scientific experiment model

Table 2: 6 - Ingredient of a new theoretical foundation of project management
Source: Koskela and Howell (2002)

2.9 Summary

Firstly, this chapter presented a detailed review of the primary research problem - delay. It provided with an overview of the nature and characteristics of the construction industry in general and the Saudi construction industry in particular. It also discussed the most common causes of delay in construction projects. It also outlined the different types of delay and their impact on performance and project timelines in particular. It also compared the different types of delay and their effects by country. The review shows that delay is a very common problem in the construction industry worldwide. The problem is much more common and severe in Saudi Arabia through. This is probably because Saudi construction firms aren't taking the issue seriously enough and aren't doing enough to find a viable solution to the problem despite their rapid growth and vast financial capabilities.

Synthesis of previous studies on delay in various countries revealed that poor project management is one of the main reported reasons for construction delay. In addition, several authors have identified these problems without practically solving them. In these studies, controllable factors related to poor project management were identified as the most often repeated causes of delay. Such factors included ineffective planning and control, poor site management, poor communication and coordination between the parties involved, delay in materials delivery and late procurement of materials. In order to improve performance, this research argues that the impact of such controllable causes of delay needs to be eliminated. For construction project management to be improved, increased efficiency and effectiveness have to be achieved in all areas. As planning and control play major roles in any project's success, particular efforts should be directed towards improving these areas.

Secondly, this chapter also presented the output of a review into project management literature. The literature suggests that the parties involved in construction projects all seek to bring about change in the industry to improve quality and increase value to clients. Scholars stress on the need to introduce alternative theoretical approaches to the study of projects. There is now a trend recognising the need to manage the flow of activities, concentrating on those that actually add value. In this respect, scholars assert that companies should explore new tools and techniques in order to achieve customer satisfaction and compete globally and that construction planning and control make key contributions to overall project success and particularly need improvements in terms of efficiency and effectiveness.

After intensive investigation of several potential ways of improving practice, Lean Project Management has been chosen as a candid solution for the problem of time and cost inefficiencies in construction projects. The next chapter discusses why Lean Management has been chosen and its relevance to this research.

Chapter 3: Literature Review - Lean Construction

3.1 Introduction

This chapter presents the outcomes of a review of the Lean construction literature. It starts with a brief insight into the concept of Lean construction and then introduces the primary principles of Lean management. It then goes on to discuss how operational waste in the construction industry can be identified and eliminated or at least reduced using a variety of Lean's tools and techniques. The second part of this chapter discusses the applicability of Lean's tools and techniques to the Saudi construction industry and highlights the benefits and challenges commonly associated with the implementation of Lean construction's tools, techniques and management principles. It ends with a review of existing Lean construction frameworks and their potentials to improve firms' operational performances.

Lean construction is an approach as much as other new approaches currently in practice has the goal of better reaching client expectation while using the least available resource to accomplish a project. It has become apparent for the need for significant implementation of the approaches and practice in order to minimise negative impact of construction activities. As a result, awareness has been raised and new approach has been developed known as the Lean Construction approach (Mossman, 2013). Therefore, moving forward, the Lean approach has been adopted and implemented in the construction sector with the aim of improving construction activities and result.

3.2 Concept of Lean in Construction

Lean construction became the new managing discipline from manufacturing thinking point of view and Lean was first discovered in Japan by Toyota (Ohno, 1988; Tezel and Nielsen, 2013). The innovation of Lean was first discovered by the popular pioneer, promoter and a chief engineer Taichii Ohno of the famous Toyota automobile company.

The aimed of the innovation is to compete with other major rivals in the industry and to become champions in eliminating waste that affect production chain directly and indirectly through Lean construction (Ohno, 1988).

Ohno (1988) defined the concept of Lean production as:

1. Pull-driven
2. Minimising waste to eliminate non-value added activities
3. Identifying and resolving defects instantly at the source of doing things right the first time
4. Continuous improvement
5. Building long term relations with suppliers
6. Building teamwork

Lean construction can successfully be achieved when the underlying relevant practices are enforced in projects including just-in-time (JIT), total quality management (TQM), total productive maintenance (TPM), continuous improvement (Kaizen), design for manufacturing and assembly (DFMA), effective and efficient human resource management and supplier management, (de Treville and Antonakis, 2006; Narasimhan et al., 2006; Shah and Ward, 2003, 2007). The whole idea, concepts and principles of Lean is targeted to generally impact on the construction process Leaner by removing potential waste that is a non-value generating activities resulting in delay and cost overrun (Koskela, 2000). Lean construction accepts the Ohno's production system design criteria as a standard of perfection (Howell, 2008). According to Howell (1999), overseeing construction under Lean is distinct from usual modern practice because it:

1. Has a stipulated and clear set of objectives in the delivery process,
2. Is aimed at maximising performance for the client at the project level
3. Designs concurrently product and process, and
4. Applies production control throughout the life of the project.

Various definitions of Lean as applied in construction are presented in Table 3:1.

Authors	**Definitions**
Shad and Ward (2007)	"It is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability".
Manrodt et al. (2008)	"Lean is a systematic approach to enhancing value to the customer by identifying and eliminating waste (of time, effort and materials) through continuous improvement, by flowing the product at the pull of the customer, in pursuit of perfection".
Construction Industry Institute (2012)	"The continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project".

Table 3: 1 - Definitions of Lean Construction

Although, Lean construction appeared to be a new innovation, its usage is similar to the current practices in the construction industry where both practices engage in meeting client expectation while decreasing waste of every resource in the process start to finish. Though, the distinction between the current practices and Lean construction is that Lean construction is based on construction managing ethics, and it has desired outcome in multifaceted, undefined, and swift projects. The implementation and application of the Lean tools and techniques has been challenged with numerous restrictions, which is due to the nature of construction projects. One of the challenged faced in the process of adopting the Lean construction tools and techniques is the inadequate investment in research and development within the construction industry (Howell, 1999). Paez et al. (2005) stated that the nature of the operation, planning, process and execution are the significant classes that highlighted the differences between manufacturing and construction. Due to these essential differences between construction and production processes, the tools of Lean production are inapplicable in construction processes and a new set of tools and techniques is therefore required. In 1992 an option known as the Last Planner system of production control was introduced with emphasises to address the relationship between scheduling and production control and is considered one of the widely used Lean construction tools (Ballard 2000). Howell (1999) asserted that Lean construction is within its maturity period and has only made some significant growth in the western world. Nevertheless, Salem (2005) stated that one of the tools and techniques such as Last Planner have been forwarded and tested around the area of sophisticated field in the last few years. Besides, Last Planner System, other tools such as daily huddle meetings, visualisation, 5S have not been extensively researched and practically tested and concrete procedures for their implementation are being developed. Lean objective is known for reducing waste of time and cost and seven types of waste has been identified under Lean construction: waiting time, overproduction, excessive motion, overstocking, delay on transportation, extra-processing, defect and rework (Kokela et al, 2013).

Lean is associated with substantial benefits especially in the area of waste reduction and improvement of organisations' supply chain communication and integration (Ogunbiyi et al, 2013). These methodologies are applied to mitigate waste and improve construction delivery: total quality management, concurrent engineering, just in time (JIT), process redesign, value-based management, total productive maintenance and employee involvement (Womack and Jones, 2003).

3.3 Lean Construction Principles

Womack and Jones (1996) found out there is inability to identify a strategic framework in interpreting Lean production into other industries in their work. The guideline principles for adopting a Lean enterprise were proposed to senior managers intending to make their organisation become Lean compliances after ascertaining the importance of organisations and it was considered valid and worthy to be adopted.

Koskela (2000) pioneered the application of Lean thinking in construction where he suggested that construction, production should be considered as a combination of conversion and flow processes for minimising waste. The principle of Lean is attributed to the manufacturing industry and was introduced and further adapted for construction (Koskela, 2000). The application and adoption of the Lean principles has been widely promoted around the world, and the initiatives have been undertaken to encourage its uptake. The Construction Industry Research and Information Association (CIRIA), Construction Productivity Network (CPN), Construction Lean Improvement Programme (CLIP) and the Lean Construction Institute UK (LCI-UK) are few examples of institutions established. Table 3:2 summarises the five principles of Lean management.

Lean Principle	**Description**	**References**
Define Value	In Lean construction, value is looked at from the customer point of view and it is defined by the customer's needs and satisfaction requirements.	Koskela, 2004; Bjornfot and Stehn 2007; Mossman 2009; Mascitelli 2002; Ballard and Howell 2004
Map Value Stream	Value stream mapping involves identifying the steps and chains in a process that create value and defining how design, planning, logistics and supply chain operations provide customer value.	Howell and Ballard 2003; Womack and Jones 1996; Green, 1996; Rother and Shook, 1998; Forbes and Ahmed, 2011
Create Flow	Flow is a key process of improving and balancing the consistent activities through which a product can be developed. It is concerned with attaining a holistic route by which a product is produced.	Fewings 2013; Koskela and Howell, 2002; Koskela 2000; Garnett et al. 1998
Establish Pull	Pull essentially means that no one upstream should produce goods or services until the customer downstream asks for them.	Womack and Jones, 1996; Dulaimis and Tanamas, 2001
Pursue Perfection	Pursuit of perfection is a constant process of adding value and elimination of non-value-adding activities (i.e. waste) in all their forms.	Dulaimi and Tanamas 2005; Bicheno, 2000

Table 3: 2 - Principles of Lean Management

3.4 Lean Waste in Construction Projects

Taiichi Ohno identified the seven wastes in his 1978 book Toyota Seisan Hoshiki, under the heading "complete analysis of waste" (Kokela et al, 2013). These included: overrun, time on hand, transport, dispensation itself, stock on hand, movement and making substandard goods. Ohno argues that the removal of these seven wastes will decrease the expense of manufacture, thus increasing profit. In setting out this of list of wastes in relation to the construction industry, Gatlin (2010) describes them as;

1. Overproduction Waste: overrun production happens when an extra product is produced when they are not needed to be productive resulting to financial cost. In

the context of construction, overproduction is concerned with situations where the contractors or sub-contractors procure additional materials, unnecessary tools and machineries or additional storage facilities which they don't really need in order to fulfil current demand. It is also concerned with the production of pre-fabricated parts ahead of schedule or based on forecasts (false demand).

2. Inventory Waste: this refers to any supply (materials or goods) in excess of what is required to build the current homes under construction. Inventory includes raw materials, work-in-process and finished goods. Though not all inventory is unnecessary waste, excess inventory can quickly build-up and tie-up money and resources. All inventories require additional handling and space. From construction project management aspect, this waste can occur when activities are poorly planned at the first instance, or inability to address the implementation stage uncertainties. Poor planning causes an imbalance between supply and demand, especially when managers use projected/estimated rather than actual demand to make procurement decisions. Optimistic demand forecasts encourage managers to procure much more material (e.g. steel, bricks, cement, prefabricated concrete structures) than actually required to fulfil current and near-future orders which in turn results in excess inventory and leads to additional costs.

3. Motion Waste: this refers to the time wasted moving materials, machineries and other resources around which don't need to be moved. Unnecessary movement of resources consumes a lot of time with no value-added to the work and therefore considered worthless in construction and production industries. The difference between work and motion is that work is to move and add value whilst motion is to move and add no value. In construction project management aspect, examples are additional process and committed time for the purpose of incompetent process layout, defect, reclaiming, and overproduction or excess inventory.

4. Waiting Time Waste: it is popularly known as delay and or waiting time from a situation whereby project needs to be put on hold because one aspect needs to be completed in order to continue in progress. Waiting waste causes more delay of the cycle with no value added to the project. For example, if activities are not planned, then there will be synchronisation issues when uncertainties happen.

5. Transportation Waste: it is a movement of goods and services from point A to point B inefficiently. A common example is transporting materials between two construction sites which involve movement, burning fuel and wasting time. Another example, could be overstock that needs to be transported back to the supplier which adds no value, but increase expenses.
6. Extra-processing Waste: over-processing is concerned with planning again and again i.e. at first place as plans are mostly generated based on planner's experience or historical data and plan might need to be changed at the implementation stage due to changes in project due to uncertainties.
7. Defects (Rework) Waste; defects are concerned with the production or construction of end-products in substandard qualities or with features that don't conform to the requirements specified by project owners. Defects necessitate rework which can be very costly for contractors and wasteful for owners.

In order to derive maximum benefit from Lean construction, implementation, there is a need to understand Lean construction priorities among all stakeholders in the construction industry. There is also need for a clear focus, and a resolution of priorities of Lean construction due to the dynamic, complex, and the fragmented nature of the construction industry. Failing to clearly defined priority of Lean construction could result to a number of concerns for potential Lean implements, organisations, as well as researchers trying to explore the essence of the concept.

3.5 Lean Construction Tools and Techniques

Construction processes have unique physical, environmental and social characteristics. Thus, the traditional tools and techniques of construction project management focus on tasks, but neglect value maximisation and waste minimisation (Koskela et al. 2002). Since Lean tools which have already proven successful in the manufacturing industry, it should also be adopted in the construction industry to achieve successful delivery of construction projects. The concepts of Lean construction centres on managing and creating an environment of continuous improvement (Bessant and Caffyn, 1997; Bhuiyan and Baghel 2005) and it empowers people to make positive decisions (Proppendiek and Proppeniek 2003). Details of the Lean tools and techniques are discussed in the following subsections. Table 3:3 identifies and defines the most popular Lean tools and techniques.

Lean Tools /Techniques	Definition of Terms	Sources
The Last Planner System (LPS)	LPS is a system which seeks to increase the degree of commitment and reliability between all stakeholders in a construction project, focusing on workflow manageability and accounting for changes to a project.	Ballard and Howell, 1994; Salem et al., 2005; Watson, 2003.
Value Stream Mapping (VSM)	VSM seeks to keep stakeholders appraised of the current position of any process, so that the supply chain can be apprised ahead of time as to whether there will be waste and how to avoid wastage. It enables an iterative approach to projects.	Arleroth and Kristensson, 2011)
Standardised Work (SW)	SWis a tool which is flexibly used to improve common approaches to construction project execution.	Toussaint and Berry, 2013
The 5S Process	The 5S process improves productivity using the processes of straightening, sorting, standardising, shining and sustaining all elements in the construction process, and reduces the time needed to source workers and materials.	Umstot, 2013
Kaizen	Kaizen comes from the Japanese and means continuous development or betterment. It is used outside of the construction industry also and seeks to promote continuous improvement in all areas of a project.	Sniegowski, 2013
Total Quality Management (TQM)	TQM identifies any problems and then suggests possible solutions to these, and then analyses the outcomes.	Marosszeky et al., 2002, CEC, 2005
Increased Visualisation (IV)	In Increased Visualisation, the idea is to make workers more aware of workflow and targets by posting material on the site which clearly marks these up.	Conte and Gransberg, 2001; Salem et al., 2005
Fail Safe for Quality and Safety	This tool helps to prevent any harm or damage occurring when any elements of a project fail.	(Ogunbiyi, 2014
Daily Huddle Meetings	These meetings are geared towards increasing employee investment in a project by daily collecting feedback and identifying problems before they escalate.	Adamu and Hamid, 2012; Aziz and Hafez, 2013; Ogunbiyi, 2014; Salem et al., 2005
First Run Studies	In FRS, tasks are remodelled so that they can be properly explored for potential errors and then solutions proposed. The parts of the process are planning, doing, checking and then acting.	(Aziz and Hafez, 2013; Ogunbiyi, 2014

The Five Why's	The five "why" questions are a tool to interrogate common areas of failure in projects and therefore identify the roots of any burgeoning problems.	ElKourd, 2009; Nielsen and Tezel, 2013
Just in Time (JIT)	This process minimises flow times such as production, the identification of resources, the need to have contractors standing by, and so on, by enabling better time management.	Ogunbiyi, 2014; Womack and Jones (2003).
Plan of Conditions and Work Environment in the Construction Industry	This tool enforces adherence to health and safety management protocols to lower workplace risk and ensure continued safety, as well as to help identify issues before they escalate.	Aziz and Hafez, 2013; Ogunbiyi, 2014
Concurrent Engineering	In this process, design is improved through the use of hands-on analysis of requirements early in the project to help integrate the various phases.	Ballard and Howell, 2003
Pull Kanban System	This system is an approach which has its roots in the car industry and was used to help pull the required materials "just in time". The name means, in Japanese, a signal or card used in these factories to control inventory when requesting new materials.	Arbulu, Ballard and Harper, 2003

Table 3: 3 - Techniques and Tools for Mitigating Construction Lag According to the Lean Method
Source: Ogunbiyi (2014); Ballard and Howell (2003); Toussaint and Berry (2013)

3.6 Lean's Impact on Planning and Control Activities

Lean's production planning and control tools have been found to be very useful tools for the management of the construction process and the continuous monitoring of planning efficiency through percent plan complete (PPC) which facilitates ongoing improvement, and stabilises the work flow of production activities (Christoffersen et al. 2001; Ballard and Howell, 2003). For example, Lean's Last Planner System or LPS have five main integrated elements: master planning, phase planning, look-ahead planning, weekly work planning and calculating the percentage of the plan completed (Ballard, 1997; Ballard, 2000; Ballard and Howell, 2003; Mossman, 2009). LPS has proven to be a powerful tool for construction project management in several countries where its implementation addressed the root causes of delay, aiming to overcome them and thus to improve construction planning practice. Also, the implementation of this technique helps firms to establish new strategies and policies that are designed to improve the efficiency of their operations especially those related to process planning and control.

3.7 Challenges in the Implementation of Lean in Construction Project Management

Lean construction is associated with many challenges and the biggest challenge for Lean is the combined effects of dependence and variation in construction as well as a project's complexity determined by the number of activities that can interact in a project system (Howell 1999). To manage these issues new forms of planning and control are required. Howell (1999) points out that measuring and improving planning system performance is the key for enhancing workflow reliability. Ballard and Howell (1999) emphasise that changing how work is structured early in the design as well as the organisation and function of both the master project plan and look ahead process are required to bring the workflow and production under control.

It is also difficult to ensure the close coordination and reliable workflow among people in construction. Human issues are emphasized in Lean construction. Lean construction initiates the shift in coordination from the centralized push to decentralized pull and deems that communication and close coordination are the way to help people understand the uncertainties and smoothly move in the face of those uncertainties (Howell 1999). As indicated by Howell (1999), people in construction lack the language and conceptual foundation to understand those physical issues concerning the underlying "physics" of production, the effects of dependence and variation along supply and assembly chains. Howell (1999) also addresses that issue of organisation and contract can only be resolved after the "physics" of production has been taken care of. In addition, cooperation is very difficult for each project participant is temporarily involved in a construction project.

In implementing Lean, construction companies can adopt the Plan, Do, Check, Act cycle. Koskela (1992) identified a process for implementing Lean construction:

1. Process – company's work should be viewed as a process with a flow of key elements such as information and material depending whether it is a management process e.g. design management or an operational process e.g. constructing a floor slab.
2. Reduce non-value adding activities - each process should be examined to reduce non-value adding activities such as movement of materials to enhance the effectiveness and efficiency of value adding processes.
3. Develop a more effective operating strategy – having developed a more effective operating strategy, the organisation of the work force must be taken into account.
4. Change the organisation culture – the culture of the organisation needs to be changed to support Lean construction. Tools need to be developed to facilitate key parts of the new process.

The implementation issues of Lean such as barriers and success factors have been identified and discussed by many studies. Porwal et al (2010) identified 12 challenges faced by construction professionals during the implementation and use of LPS. The challenges fall into two categories: (1) challenges faced during the implementation phase, and (2) challenges faced during the use of LPS. The Following are lists of the challenges:

Implementation Challenge

1. Lack of training
2. Lack of leadership/failure of management commitment/organisational climate
3. Organisational unwillingness and resistance to change
4. Stakeholder support
5. Contracting and legal issues/contractual structure
6. Partial implementation of LPS and late implementation of LPS

User Challenges

1. Human capital and lack of understanding of new systems; difficulty making quality assignments/human capital-skills and experience
2. Lack of commitment to use LPS and attitude toward new system
3. Bad team chemistry and lack of collaboration
4. Empowerment of field management/lengthy approval procedure from client and top management
5. Extra resources/more paper work/extra stuff/more meetings/more participants'/time Physical integration.

This research has also found that lack of training, poor deployment of management tools, resistance to change and government bureaucracy and instability were common barriers to Lean implementation (*Refer* to Section 5.3.5). According to the survey data, bureaucracy and instability significantly hinder the Saudi construction industry's transition to Lean. This was followed by "resistance to change" and "lack of proper training" as the second and third most significant barriers respectively. However, the data from the interviews puts greater emphasis on information sharing and planning and control (*Refer* to Section 5.2.1). This research has found that without the use of real-time planning and control techniques, and without the use of modern project management practices to control costs and reduce the risk of delays, Lean will not produce the desired results.

3.8 Benefits of Lean Construction Project Management

Lean construction is one of the strategies for improving construction performance. The Lean approach in construction project management focuses on the removal of all forms of wastes from construction processes to allow more efficiency. Existing studies have suggested theories which reinforce Lean as a method for optimising resources, improving safety, productivity, working conditions and overall, the social, environmental, and the economic bottom line (Nahmens and Ikuma, 2012). The principles and techniques of Lean construction emphasis on making a justifiable change by highlighting on efficient, waste-free and safe flow, storage and handling of materials to minimise cost, energy and resource consumption, and provide value for clients and end users (Nahmens and Ikuma, 2009). Consequently, it is reported by Mossman (2009), that some of the benefits of implementing Lean in a construction project are:

1. More satisfied clients
2. Productivity gains
3. Greater predictability
4. Shorter construction periods
5. Operatives able to make better money
6. Sub-contractors able to make better money
7. Improved design
8. Reduced cost, less waste
9. Improved health and safety
10. Improved quality, fewer defects

This research has also found that the adoption of Lean principles and the implementation of Lean's Kanban's rules in particular provide construction firms with numerous benefits which include, but not limited to: better communication, closer collaboration, fewer defects, improved quality, stronger stakeholder relationships, enhanced information flow, and most importantly greater bottom-line results (*Refer* to Section 5.2.4). The interviewees stressed that the adoption of Lean-friendly practices such as Kanban and collaborative planning often enabled construction firms to reduce costs and boost operational efficiency. The data from the survey also confirmed that Lean's adoption is typically associated with significant improvements, particularly in design, project management, and organisational management (*Refer* to Section 5.3.3). These findings are consistent with the findings of Koranda et al., (2012) who developed a framework for the implementation of Lean tools and techniques in a construction project (*See* Figure 3.2). According to the conceptual arguments of the framework, Lean's principles can be positively applied to any aspect of an organisation's management and provides a method for achieving organisational goals (Soltero, 2007).

These goals may be related to cost reduction, quality improvement, reduction of environmental impact, and improvement in safety.

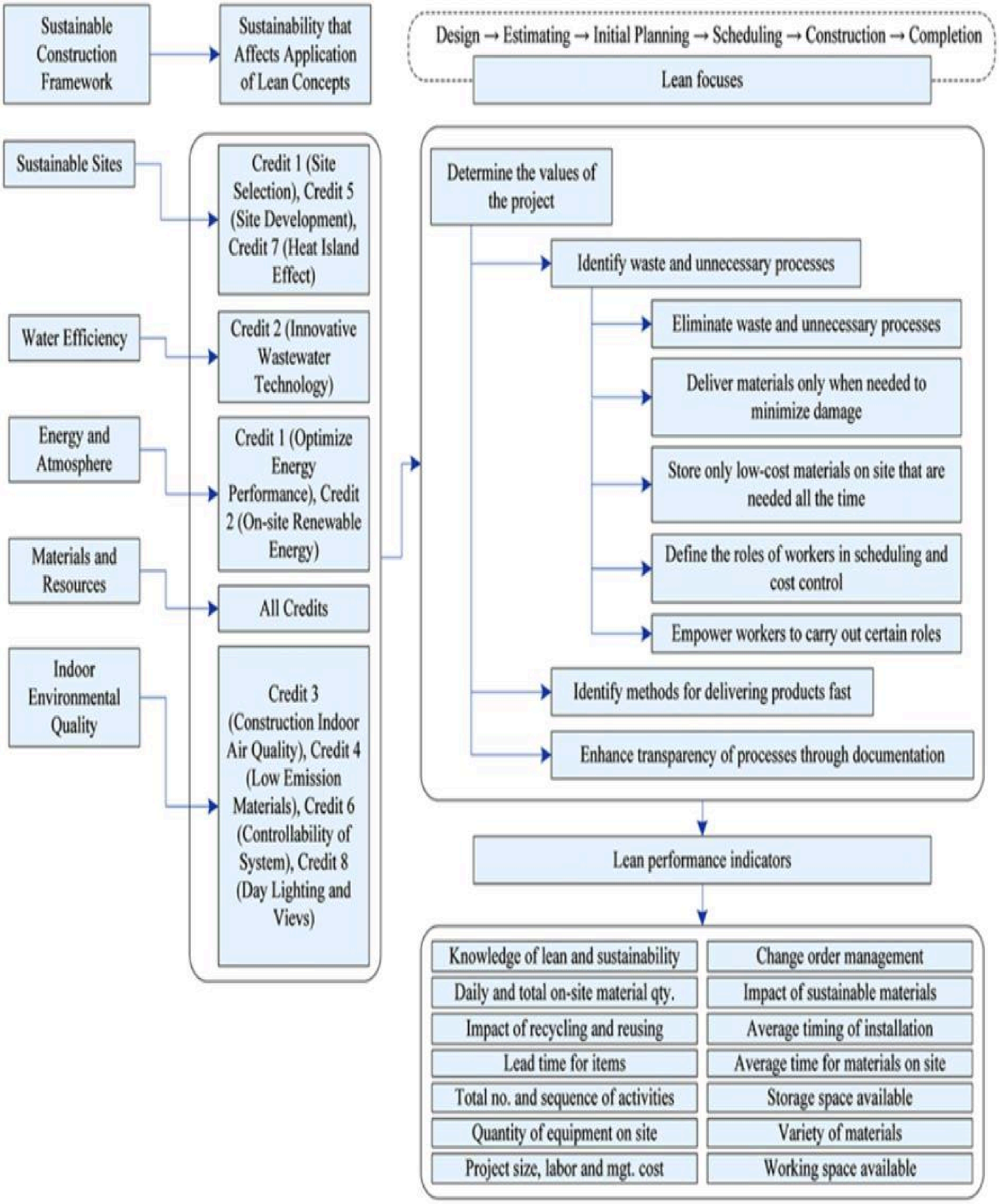

Figure 3: 1 - Framework for Implementing Lean Techniques
Source: Koranda et al (2012)

3.9 Review of Existing Lean Construction Frameworks

Based on the review of literature some examples of frameworks are presented below:

3.9.1 Lean - A Framework

Hines et al. (2004) developed a framework for the development of Lean concept. This framework is based on the work of McGill and Slocum (1993), using organisational learning theory to set a vision to help companies see where they can evolve in their Lean thinking. Figure 3.3 presents the framework for the development of the Lean concept based on the strategic and operational level.

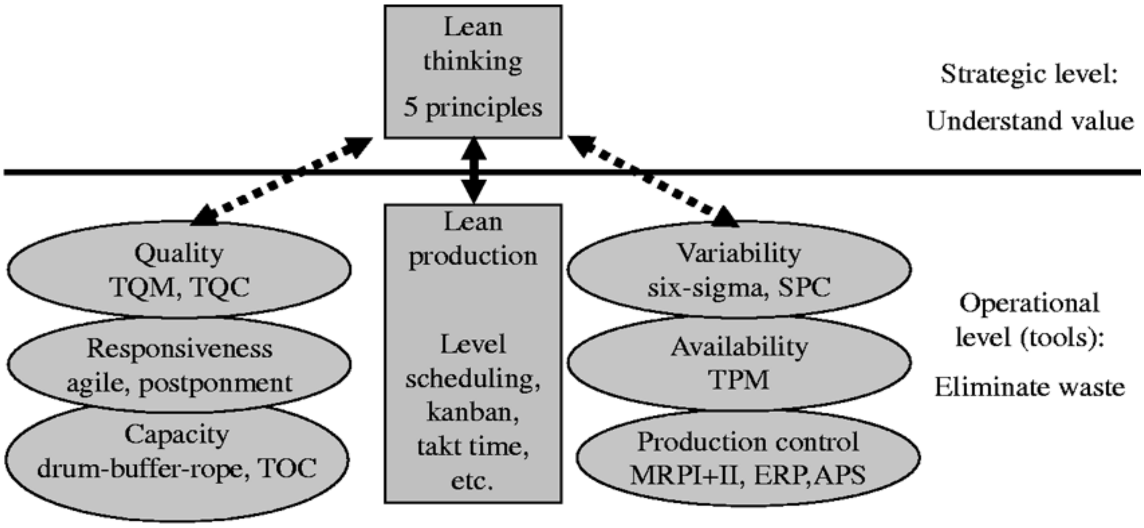

Figure 3: 2 - Lean - A Framework
Source: Hines et al (2004)

In the above framework, Lean construction exists at two levels: operational and strategic. Various contingents are taken into account when deploying policies such as their size, industrial sector, industrial dynamics and technology employed. Based on the fourth Lean value system stage, a unique contingent approach was created using a range of tools drawn from diverse management approaches such as agile manufacturing, Lean manufacturing, system dynamics Six Sigma, marketing theory of constraints, and revenue management.

Although this framework provides an overview of which pro-Lean tools firms could adopt to improve their operational performance, it does not focus specifically on addressing the problem of delays and cost overruns. It only provides an outline of what should be done, but it fails to conceptualise an improvement process or provide a roadmap which details how the use of Lean construction's tools like Kanban could improve construction firms' cost and time efficiencies.

3.9.2 Lean Enterprise Architecture

The Lean Enterprise Architecture (LEA) context was developed by Mathaisel (2005). The purpose is to redefine enterprise re-engineering around the design, construction, integration and implementation of an enterprise using this framework. Figure 3:4 shows the framework and is based on Lean principles and system engineering methods widely used in the construction and manufacturing industry. It uses a multi-phase approach, which is structured in the transformation life cycle phases and portrays the flow of phases necessary to initiate, sustain and continuously refine an enterprise (Mathaisel, 2005). Even though, the framework is accepted and useful, it has a limitation that it does not possess a definite process for defining performance requirements or improvement metric system that are necessary for successful implementation of engineering process and architectural. It also fails to demonstrate how upstream and downstream operations may be streamlined in order to achieve optimal operational performance. In fact, it's more of a 'change management' model than a Lean construction implementation framework. It focuses more on the life cycle of implementation processes than on what really needs to be done in order to improve construction firms' operational efficiency. As such the framework cannot be implemented in this research.

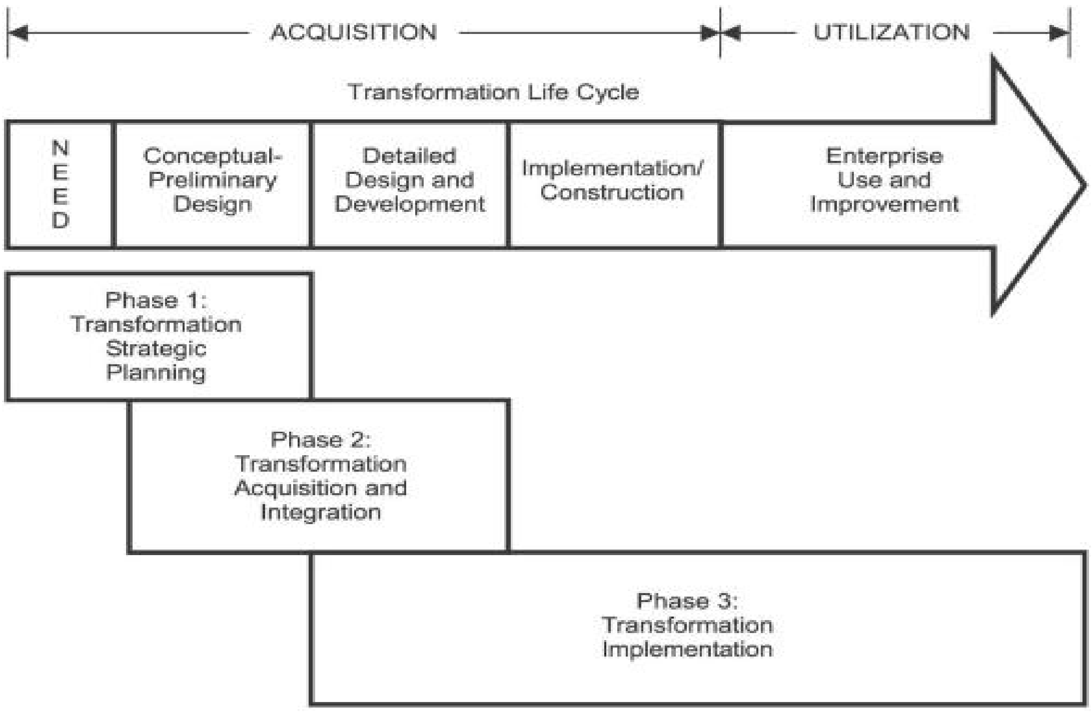

Figure 3: 3 - Lean Enterprise Architecture Phases
Source: Mathaisal (2005)

3.9.3 Lean Assessment Tool

Lean assessment tools for construction projects was developed by Salem et al. (2006) which provides a checklist for Lean construction practices and to ensure compliance in the construction sector. Figure 3:5 shows the Lean assessment tool: Spider-web diagram. The Lean assessment tool was based on the observation of six Lean tools application on construction sites. The assessment expected outcome of the construction project, but it is important to note that this framework does not provide a self-assessment tool with the capability of breaking down the strategic and management issues. It barely provides an indication of how well a firm is performing against the use of different Lean construction tools and techniques. It does not provide a clear structure, process or roadmap which construction firms could use in order to optimise their performance. It is clearly not efficiency-focused and can't be used to address the problems of delays and cost overruns. Therefore, it is not at all applicable to this research.

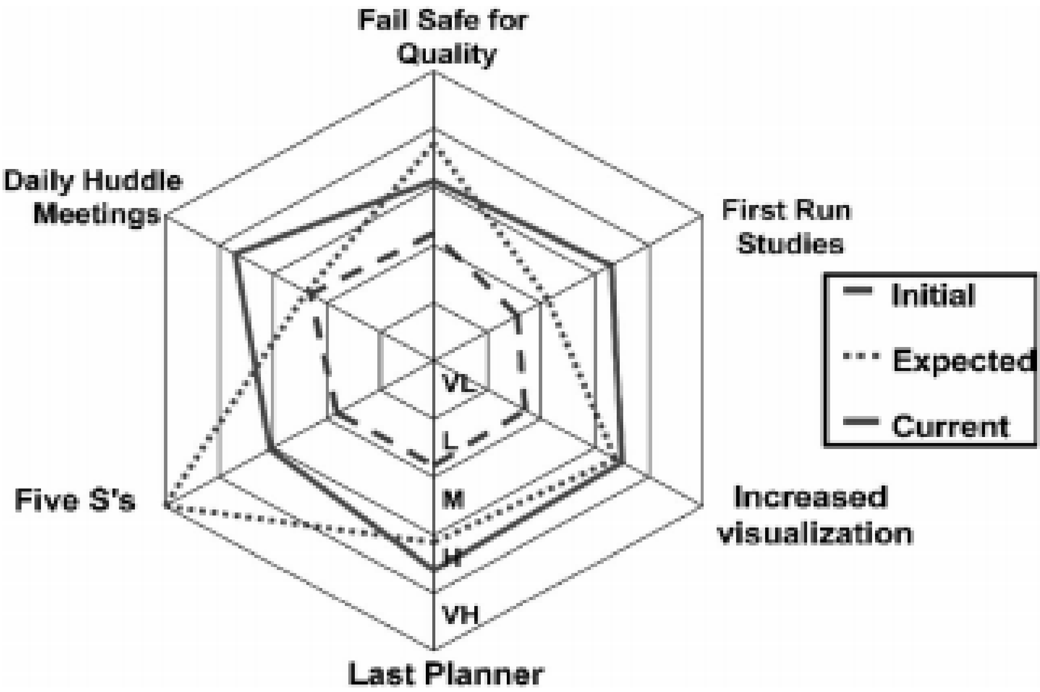

Figure 3: 4 - Lean Assessment Tool: Spider-web Diagram
Source: Salem et al (2006)

3.9.4 The Lean Project Delivery System

The Lean Project Delivery System (LPDS) is a conceptual framework developed by Ballard (2000) to guide the implementation of Lean construction projects. It was developed as a set of interdependent functions and as implementation tools in the construction and manufacturing sectors. It is made up of five phases: project definition, Lean design, Lean supply, Lean assembly and use. Each of the phases contains three modules and is represented as a triad. Each triad overlaps the succeeding triad to include at least one common module. Some important features of LPDS include downstream players in the planning process, conceptualising the project delivery as a value generating process, and creating a reliable workflow amongst the project participants (Ballard, 2000).

The domain of Lean project delivery is defined by the intersection of projects and production systems and is therefore fully applicable to the delivery of capital projects, which include the formation of a temporary production system in the form of a project team that consists of owner, architects, engineers, general contractor and sub-contractors. The framework is very useful for project control. Figure 3:6 illustrates the LPDS system.

However, although the LPDS system provides details of the different processes that firms must consider and how each process is interconnected and interrelated to other processes, it does not outline the steps which firms should take in order to optimise their operational performance. For example, it does not clarify what construction firms need to do in order to mitigate the risk of delays and cost overruns. Hence, this framework is inconsistent with the conceptual and theoretical needs of this research.

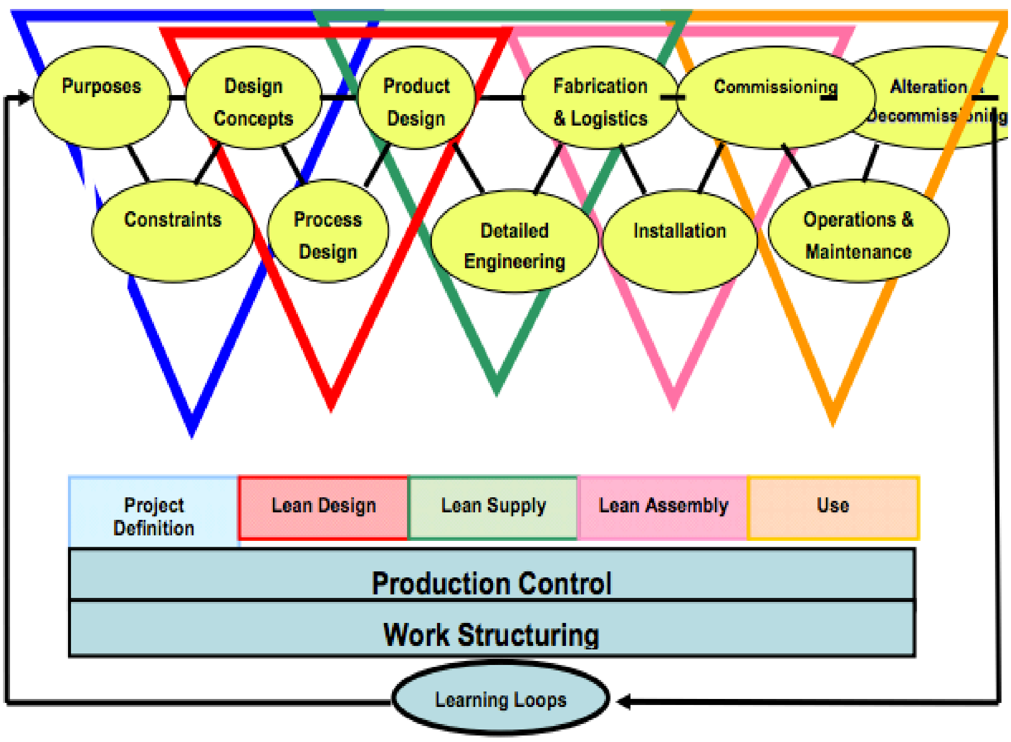

Figure 3: 5 - LPDS System
Source: Ballard (2000 and 2006)

3.9.5 The 4P Model of Lean

The 4P model of Lean was developed by Liker (2004). The model is based on the "Toyota way" and incorporates the 14 key management principles. Continuous improvement and learning is at the top of the pyramid followed by development of people and partners, process orientation and long-term thinking at the base. According to Liker (2004), managing the 4P-model is seen as a prerequisite for sustainable improvements. The 14 principles are classified under each of the 4P's as shown in Table 3:4.

This model does not provide a process or structure which organisations can follow in order to successfully implement and operationalise the principles of Lean construction. Instead, it provides an abstract overview of Lean components which organisations should consider and what each component or principle means.

4P's	Principles
Philosophy	- Base management decision on a long term philosophy, even at the expense of short-term financial goals.
Processes	- Create continued process flow to bring problems to the surface - Use pull system to avoid over production - Level out the workload - Build a culture of stopping to fix problems, to get quality right the first time.
People and Partners	- Grow leaders who thoroughly understand the work, live the Lean philosophy, and teach the Lean philosophy to others. - Develop exceptional people and teams who follow the organisation's philosophy. - Respect for the organisation's extended network of partners and suppliers by challenging them and helping them improve.
Problem solving	- Go and see for yourself to thoroughly understand the situation - Make decision slowly by consensus, thoroughly considering all options; implement decisions rapidly - Become a learning organisation through relentless reflection and continuous improvement.

Table 3: 4 - The 4P Model of Lean
Source: Liker (2000)

3.9.6 Cost-Time-Profile

Cost-Time-Profile (CTP) was proposed by Rivera and Chen (2007) a useful tool for the evaluation of the improvements achieved by the implementation of Lean tools and techniques. The CTP is an assessment tool to measure the expected impact of a change in the production process and is used in manufacturing industries as well as construction. The CTP, however, is not an implementation model or framework. It does not offer a process or a roadmap for Lean construction's implementation. Instead, it enables managers to build cost-time profiles for individual processes. This model may be useful for decision-making, but not necessarily for the management of Lean construction's implementation.

3.9.7 Framework for Describing the Levels of Lean Capability

Jorgenson et al. (2007) presented a framework for describing levels of Lean capability. This framework was based on a literature review and experiences of some selected companies. The framework described the developmental stages that support the Lean capability development and Lean sustainability. Five different levels of Lean were identified which are: sporadic production, basic Lean understanding and implementation, proactive Lean culture, strategic Lean intervention and Lean in the Extended Manufacturing Enterprise (EME). The limitation of this framework is that it focuses on manufacturing environments. It also only outlines the different phases of Lean diffusion, but it does not provide details of how individual Lean tools or techniques could help firms to improve their operational performance. It also does not provide a detailed process or a roadmap for the operationalisation of Lean management principles.

3.9.8 Impact Assessment Framework

Hayes and Pisano (1994) stated that Lean could be seen as an intended direction, not as a state or an answer to a specific problem. Therefore, there should be a way to measure progress made in a Lean implementation effort. Based on this, Achanga (2007) developed a framework for assessing the impacts of implementing Lean within SMEs at the conceptual design stage. This framework was targeted at designers of Lean processes to enable them to adjust Lean inputs so that the costs of implementation are greatly reduced. According to the author, practitioners involved in the design of a Lean process within companies tend to omit certain critical aspects of the fundamental ingredients within their planning process in the implementation drive. Therefore, it was suggested that organisations should look at how best to design the entire Lean implementation process at the conceptual stage of the project life cycle. However, this framework doesn't provide a structural process which can be used by construction firms to successfully implement individual Lean techniques and tools such as Kanban. It is also not problem-oriented; thus, it can't be used by construction firms to address the problems of time and cost overruns.

In summary, the existing Lean frameworks do not provide much assistance with the issues of delays and cost overruns. They either lack the much-needed focus on individual Lean management processes' implementation and operationalisation, or fail to provide clear sets of steps and processes which construction companies could follow in order to optimise their operational performance. Even the frameworks that provide a clear set of processes and well-thought conceptual structures are inconsistent with the needs of this research. This research focuses mainly and specifically on time and cost inefficiencies and on the operational circumstances of Saudi construction firms. Hence, in order to fill this gap in the author set out to develop a Lean project management framework for the construction industry to improve the time and cost efficiencies of Saudi construction firm's operations.

3.10 Lean and Project Management Synergies

There are clearly some synergies between the principles of Lean management and project management. After all, the idea of the Lean approach to operations management continues the idea of Henry Ford, who is quoted as saying ‘if it does not add value it is a waste’ (Maylor, 2010). Table 3:5 illustrates some of the similarities between Lean's principles and project management practices as discussed by Maylor (2010).

Lean management	Project Management
Integrated single-piece workflow produced in time	Information treated as inventory and processed immediately rather than spending long period waiting.
Absolute elimination of waste	See seven ‘waste’ (section 3.4).
Focus on global rather than local optima	Focus on achieving the goals of the organisation through this and other project activities and considering the project in this light rather than as a totally independent item (develops the idea of the role of the stakeholders).
Defect prevention	Defect prevention
Multi-Skilling in team based operations	Multi-Skilling in team based projects
Few indirect staff	Few indirect staff

Table 3: 5 - Lean Principles Applied To Project Management

Figure 3:7 also demonstrate how construction firms can tap into the synergies which exist between Lean thinking and project management. For example, they could be used to manage waiting time waste or delay in the planning and control processes of construction projects. Figure 3:7 conceptualises how the different parts relate with one another in achieving the desired outcome, which is to manage delays on the project. However, to achieve this desired outcome, the organisation has to put in something (input) into its system, which then engages in some processes to achieve the desired outcome. In doing so, the system may encounter some challenges that need to be addressed using certain strategies so that the desired outcome can be achieved. Some measures may also have to be undertaken to address any negative impact that may be associated with the processes.

Figure 3:7 comprises of the following sections: the input; processes; challenges; strategies for overcoming the challenges; negative impacts; strategies for avoiding or addressing the negative impacts; and positive outcomes of the overall framework. This entire process of the framework is further expatiated below:

- **Input**

The input is one of the important elements that is added to the system to achieve some targeted results. It is therefore what is required by the organisation to do in order to eliminate waiting time waste or delay on its project sites. The input is to engage in the holistic application of Lean thinking in the planning and control processes in the project. Lean project management commences with an understanding of Lean principles. The organisation has to first ensure that its employees understand and apply the Lean principles. The application of these principles is, thus, the main input in the roadmap to adoption of Lean thinking.

- **Process**

After an element of the project is determined, it is now important to process what has been imputed to earn a desire result. This process, in the course of this research will involve applying the Last Planner System to eliminate waiting time waste or delay in the planning and control stages of the project. Lean Construction considers planning and control to be complementary and dynamic processes maintained during the course of the project. Planning defines the criteria and creates the strategies required by the project objectives. At the same time, control makes sure that each event will occur in the planned sequence. It is, therefore, necessary for an organisation to proactively apply the Last Planner System in order to achieve its benefit. In doing so, empirical data must be gathered and validated.

- **Challenges**

The implementation of Lean in construction project management is usually confronted with challenges of a different nature as discussed in the previous sections. These include lack of training, organisational unwillingness and resistance to change among others. Though these are challenges facing Kanban practices across different countries, contact with the Saudi Arabian construction firms would help in identifying certain challenges peculiar to them.

- **Strategies for Addressing the Challenges**

These are the different ways of addressing the challenges to Lean Project Management. The challenges are not to be ignored; they must be addressed in order to achieve a desired goal. In an attempt to identify ways of addressing these challenges, Suresh et al., (2012) identified awareness creation of Lean programs, training and development on Lean principles and techniques. There seem to be inadequate strategies reported in the literature. Thus, it becomes necessary to explore other strategies that could be used to address the numerous challenges associated with Lean project.

- **Negative Impacts**

Despite the benefits of Kanban System techniques reported in the literature, a number of studies (Ballard et al, 2007; Ballard et al, 2009; Porwal et al; 2010) suggest that the application of Lean techniques in the construction sector may result in some negative impact on construction project management. Though this experience has not been identified in the literature, this has been investigated further through interviews with employees of the Binladin Construction Company. Nevertheless, the occurrence of such negative impacts must be avoided or addressed in order to realise the targeted benefits.

- **Strategies for Addressing the Negative Impacts**

Although, efforts are made to carry out projects, some negative impact may occur to affect the smooth running of the project with Lean practitioners. Depending on the nature of the negative impacts, recommendations can be drawn on how the negative impacts can be addressed to achieve a positive outcome from the point of view between literature and practical views.

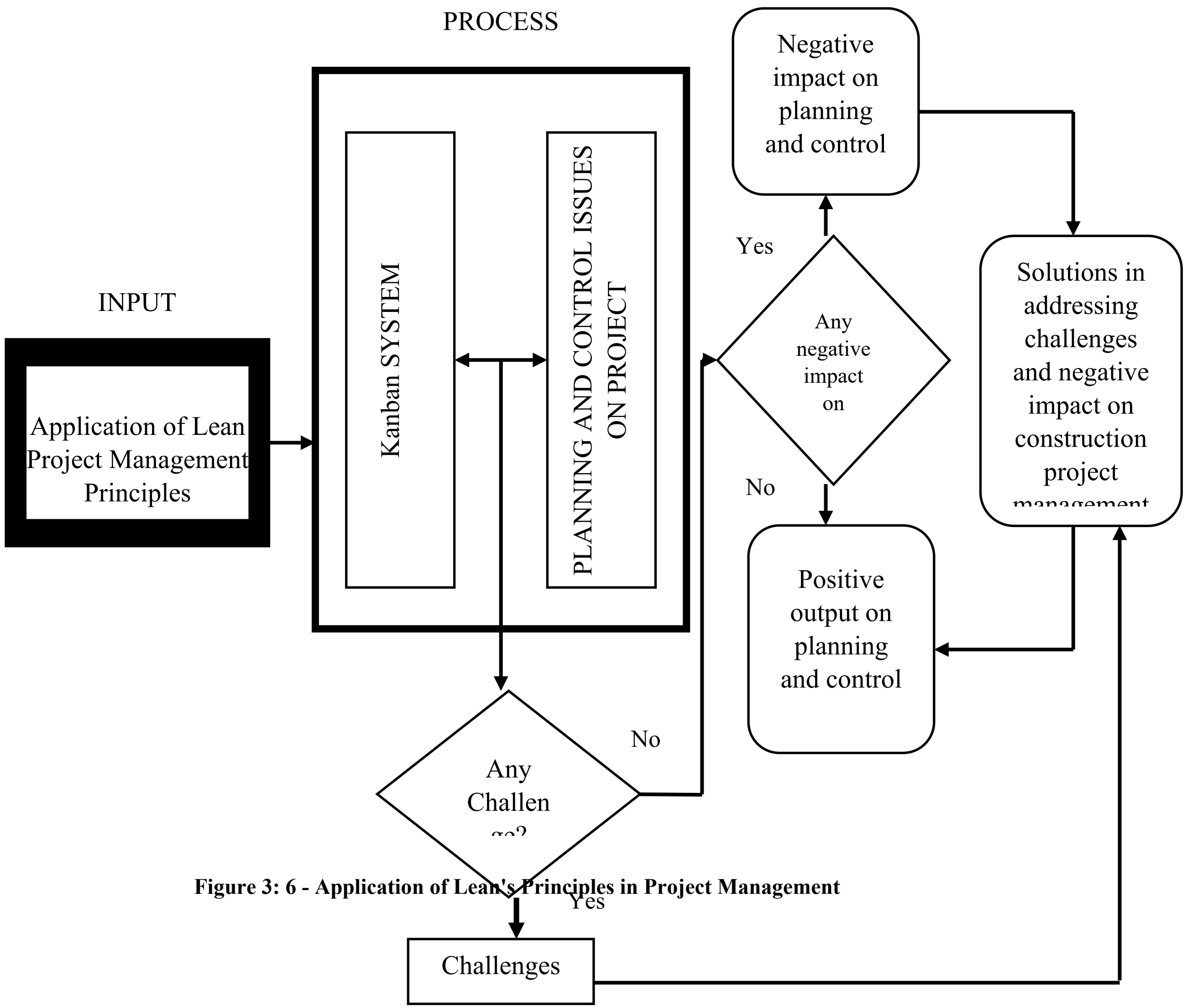

Figure 3: 6 - Application of Lean's Principles in Project Management

- **Outcome**

After the elements has been imputed and processed, an outcome is expected, which a result is anticipated to have passed through some underlying industry challenges. However, the challenges are also expected to be addressed going forward to achieve a desired goal. Some of the key expected outcome is improvement in construction delay. The result could cost reduction, employee welfare, productivity, efficiency or trust of reputation

3.11 Summary

This chapter focused on the Lean approach in construction through a review of literature centred on Lean construction in the wider context of the construction industry. A review of Lean tools and techniques, benefits of Lean in construction project management and the priorities of Lean construction are also included in this chapter based on a critical review of extant literature. This chapter also included a review of the different approaches to evaluating and assessing an organisation's operational performance.

The outputs from the literature review indicate that Lean construction much like current practice has the goal of better meeting customer needs while using less of everything. There has been the need for widespread implementation of practices and approaches that would reduce the negative impact of construction activities. This has raised the awareness of the construction industry to adopt Lean's principles. Hence, Lean has been implemented within the construction industry as a means of improving construction activities.

Chapter 4: Research Methodology

4.1 Introduction

This chapter describes the research methodology that has been adopted for this research study. A research methodology has a direct impact on the strength and generalisability of the research (Yang et al, 2006). The research methodology is concerned with the steps, processes and methods that a researcher takes or follows in order to achieve the aims and objectives of his/her research. This entails all the tools, techniques and procedures that facilitate or support the collection and analysis of necessary primary and secondary data. This chapter evaluates, discusses and justifies the scientific methodological steps that the author has taken in order to successfully investigate how Lean management principles, tools or techniques may help construction project managers to improve the operational performance of Saudi construction firms. This chapter starts by outlining the research's aim and main questions. It then moves on to evaluate the strengths and drawbacks of different components of the research methodology using Saunders' et al. (2012) "research onion" as a framework. It ends with an overview of Design of Experiments (DoE) and Discrete Event Simulation (DES) and details how they have been used to simulate the benefits and implications of adopting Kanban's rules by the Binladin Construction Company / BCC.

4.2 Research Scope

This research has a definitive and narrow scope. First, it doesn't study all the challenges that hinder Saudi construction firms' abilities to achieve optimal operational performance. It is primarily focused on cost overruns and delays. It explores the possibility of adopting Kanban's 6 rules of improvement as a means solving some of the Saudi construction industry's most persistent problems. Second, it's based on the experiences and operational context of a single construction firm; namely, the Binladin Construction Company. Third, this research pays greater attention to the construction phase than the pre-construction stages such as planning and development. This means that pre-construction factors that impact on firms' performance have not been studied in this research. Fourth, the research has focused primarily on the Saudi construction industry and no attempts have been made to incorporate the contexts of other countries. Fifth, only the experiences and operational context of a single focal construction firm have been considered. The role played by sub-contractors in shaping the operational performance of focal firms has not been studied sufficiently.

4.3 Development of Research Methodology

Saunders et al. (2009) describe research as "something that people undertake in order to find out things in a systematic way thereby increasing their knowledge". Saunders et al. argued that a good research methodology ensures data is collected and interpreted systematically, and that there is a clear purpose to find things out. This study's methodology has been based primarily on Saunders' et al. (2012) research onion framework. As we all know, ideas about research methodology are continuously evolving. In this respect, Saunders et al. (2012) have improved the 'research onion' model twice. In the first instance, the authors added two more layers (concerned with 'research strategy', and 'time horizon and data approach') within the research process as shown in Figure 4.1 and made the second improvement in 2012, where the authors expanded the research onion to include a layer concerned with 'research choice' which covers thoughts about mono-methods, mixed-methods and multi-methods.

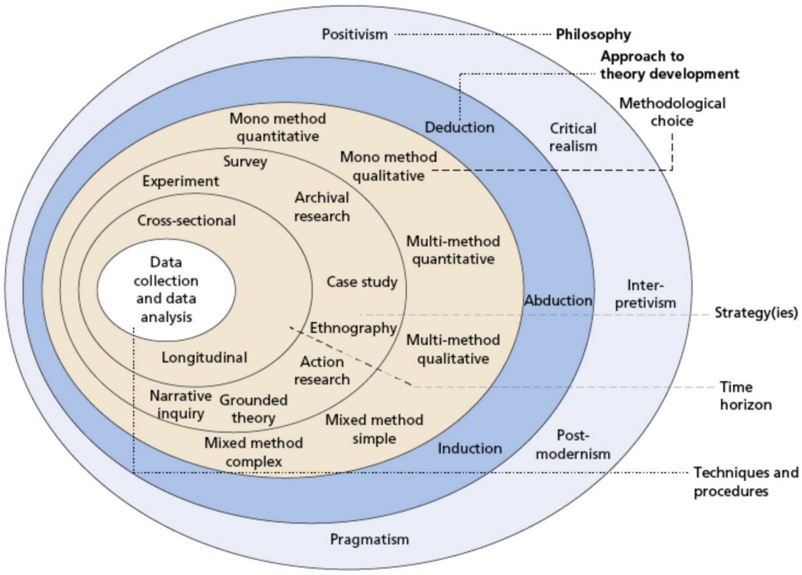

Figure 4: 1 - The research 'Onion'
Source: Saunders et al. (2012)

4.4 Research Philosophy

Saunders et al. (2012) describes philosophy as the belief and thinking that an individual has about knowledge and how it is created and developed. It is a way of examining social phenomena from which particular understandings of these phenomena can be gained and explanations attempted (Saunders et al, 2012). Research philosophy portrays the researcher's standpoint against the research problem. It offers a framework consisting of theories, methods, and ways of defining data, which explains the relationship between data and theory (Easterby-Smith et al, 2012; Collis and Hussey, 2003). It describes the theory of research in a particular field and explains the assumptions that underlie the research approaches (Maylor and Blackmon, 2005). These assumptions mainly concern the nature of reality and how we can know reality. There are several reasons why it is important for researchers to be aware of their philosophical stance. First, understanding one's own philosophical stance helps to clarify research designs. This does not only involve considering what kind of evidence is required and how it is to be gathered and interpreted, but also how this will provide good answers to the questions being investigated in the research (Easterby et al. 2012). Second, knowledge of philosophy can help the researcher to recognise, which design will work and which will not. It indicates the limitations of a particular approach. Third, it can help the researcher identify, and even create, designs that may be outside their past experience. It may also suggest how to adapt research designs according to constraints of different subject or knowledge structures.

Saunders et al. (2012) indicated that there were four research philosophies to choose from; namely, positivism, interpretivism, pragmatism, post-modernism, and realism. Each of these philosophies has a number of strengths and some weaknesses depending upon the context and research nature. In this research, the author has adopted a hybrid philosophical stance which combined the strengths of interpretivism with positivism. This research is predominantly interpretivist, but some of its elements (e.g. quantitative survey) were based on positivism. Both interpretivism and positivism are concerned with the nature of reality-what is considered to exist and, just as importantly, what does not exist in the environment studied (Maylor and Blackmon, 2005). Positivism necessitates an objective approach to data collection and analysis, whereas the interpretivist philosophy facilitates and allows a subjective approach to research. Moreover, interpretivism focuses on people's experiences and understandings of reality which enables researchers to account for the complexities of socially-constructed research subjects, whereas positivism focuses on understanding the relationships between causes and effects objectively by using verifiable, replicable and systematic data collection and data analysis methods.

Undoubtedly, choosing an appropriate philosophical stance helps researchers to achieve their research aim without comprising their research's integrity. Knight and Ruddock (2009) report that the most important consideration for researchers is the need to be aware of the influence of the methodology the researchers choose and that the researchers must also highlight their own philosophical preference. Knight and Ruddock also discussed the arguments presented by Richard Rorty (1931-2007) about the varying perspectives that exist about the world, and investigate the mediation between language and culture, concluding that knowledge is most probably relative to interests, and is largely fixed in cultures. This is a vital point to acknowledge with respect of this particular research, since it is conducted in a multicultural environment, the data being collected in Saudi Arabia, where there is a different language, and the culture is different to that of the UK.

There are several reasons which encouraged the author to embrace interpretivism as research philosophy and to complement it with positivism (*Refer* to Table 4:1). First, interpretivism is consistent with the aim and purpose of this research study, which seek to explore the benefits, enablers, barriers and implications of Lean construction's tool's adoption by Saudi construction firms. The use of interpretivism enables researchers to understand social processes, and to take into account the complexities and contextual factors of the processes they are investigating. Secondly, the interpretivist philosophical stance facilitates understanding of how and why questions and enables researchers to conduct more in-depth analysis of the research problem that what is possible using other philosophies. Thirdly, the employment of positivism as a complementary philosophical stance strengthens the author's position as positivist research methods facilitate the collection of large amounts of verifiable, quantitative data using a variety of techniques. The author was convinced the interpretivism would enable him to investigate the research issue in the right level of depth, while positivist methods would allow him to produce reliable and generalisable conclusions.

Type of Philosophy	**Description**	**Commentary**	**Decision**
Positivism	Positivism necessitates an objective approach to data collection and data analysis. It focuses on identification of causal relationships between causes and effects by using verifiable data collection and analysis tools and procedures.	The author adopted a hybrid philosophical stance which complemented interpretivism with positivism. Positivism has been adopted because it provides the author with a robust, reliable, scientific and objective approach to data collection and data analysis, which are crucial for making generalisations about the most common barriers and enablers of Lean construction in the context of the Saudi construction industry.	Partially Adopted
Critical Realism	Critical realism assumes that there is a	This theoretical stance does not apply to this research.	Rejected

	difference between the 'real' world and the observable one. Realists claim that the real work can't really be observed and that it exists independent from human perceptions.	Despite its several strengths, The author has rejected this philosophy because it fails to account for the complexity of socially constructed realities associated with the success and failure of implementation processes in the culturally sensitive workplaces like the Saudi construction industry.	
Interpretivism	Interpretivism allows a subjective approach to data collection and data analysis. It focuses on people's experiences of reality. It allows authors to account for the complexities of socially -constructed issues.	This study is predominantly interpretivist, but some of its elements (i.e. survey) was based on positivism. The author has decided to use interpretivism because it offers and provides him with the means and the flexibility to investigate the socially constructed realities of Lean construction implementation successes and failures in the context of Saudi construction firms using the case-study of a Saudi construction firm.	Adopted
Post Modernism	This philosophy is more common in the study of cultures and political power. It has a sceptic and subjective approach to understanding reality and emphasises the role of ideology in shaping reality and people's attitudes and behaviours	This philosophy is not at all consistent with the needs of this research. Although this philosophy is relevant to this research particularly in terms of studying complex research problems using meanings and experiences, it doesn't fit well with this research's needs. It is for this reason the author rejected this philosophy.	Rejected
Pragmatism	Pragmatism focuses on what really works. It allows researchers to use different methods to deconstruct research phenomena and study the truths which make up people's realities.	This philosophy's arguments and assumptions are not at all consistent with the needs of this research. The author rejected this philosophy because it is more concerned with producing practical results and finding viable solutions to problems than with the creation of new theoretical knowledge and generalisations. This research did not seek to find	Rejected

		solutions to a practical problem, but rather sought to explore the benefits, enablers, barriers and implications of Lean construction implementation in the Saudi context. So this philosophy does not fit well with this research's needs.	

Table 4: 1 - Selection of a Research Philosophy

4.5 Research Approach

Saunders et al. (2012) indicated that researchers could adopt one of three research approaches, namely, induction, deduction and abduction. The deductive approach (top-down approach) is a logical process of reasoning which begins with a general theory (what is known about in a particular domain) and moves toward inferring a more specific hypothesis which is subjected to empirical scrutiny against observations. In contrast, the inductive approach (bottom-up approach) moves the other way from specific observations towards detecting patterns and formulating some hypotheses, ending up in broader generalisations and theories (Trochim and Donnelly, 2008). Figures 4.2 and 4.3 shown below illustrate an overall view of each of these approaches.

The author has decided to use a combined research approach which allows him to tap into the strengths of both induction and deduction (*Refer* to Table 4:2). A combined approach of abduction enabled the author to move back and forth between deduction and induction, which allowed him to use the existing theories to develop research assumptions and then study the assumptions inductively using direct observations, experiments and interviews with professionals.

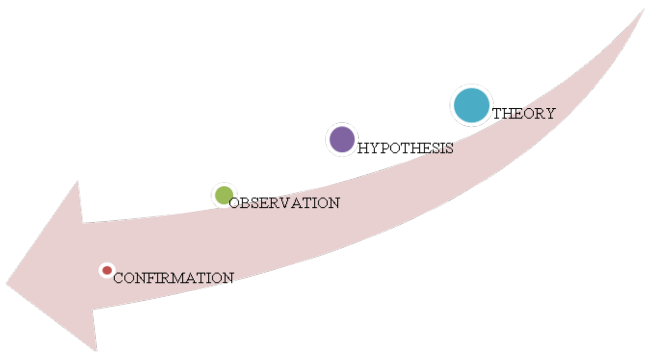

Figure 4: 2 - Deductive approach
Source: Burney (2008)

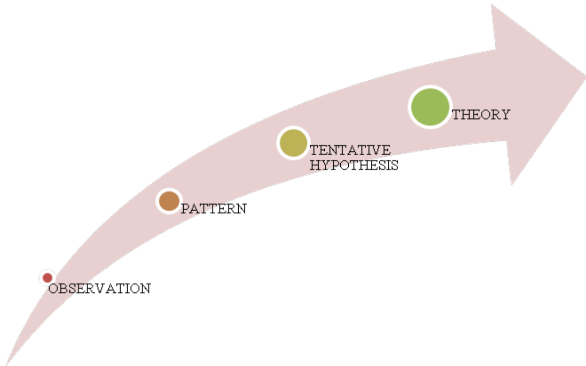

Figure 4: 3 - Inductive approach
Source: Burney (2008)

Type of Approach	Description	Commentary	Decision
Induction	Induction is a bottom-up approach that starts with observations or interviews and moves toward much broader generalisations and the theory developed.	This approach is applicable to a great degree to this research, but it needed to be complemented by deduction. The author's decision to use induction as the primary research approach is based on the fact that he needs to investigate a popular research problem in a unique context (i.e. in the context of Saudi construction firms). There are not many empirical studies in the literature which have objectives similar to this research's and that's why the author has decided in favour of using induction.	Partially Adopted
Deduction	Deduction is a top-down approach which begins with a general theory and moves to inferring hypotheses which are empirically validated or rejected.	This approach was used to complement the induction approach. The deductive research approach is useful for researchers who conduct survey research whose questionnaires are designed based on the outputs from academic literature and this is why the author decided in favour of using this approach to research. This approach has enabled him to identify the most common enablers, barriers, benefits and the implications of Lean construction adoption and to	Partially Adopted

		study them in the context of Saudi construction industry.	
Abduction	Abduction combines the induction and deduction approaches to suit the specific needs of studies	The author decided to use the abduction approach because it allowed him to tap into the strengths of both induction and deduction. Abduction is useful for research studies like this one where there is a need to explore unique issues with little or no pre-existing research/knowledge as well as pre-researched subjects simultaneously. Basically the abductive approach provides the author with the right level of flexibility to shift from induction to deduction based on the needs of the research.	Adopted

Table 4: 2 - Selection of a Research Approach

4.6 Methodical Choices

According to Easterby et al (2012), methods are the instruments and processes for gathering research data, analysing it and drawing conclusion from it. A method is a systematic and orderly approach taken towards the collection and analysis of data so that information can be obtained from those data (Jankowicz, 2000). Consequently, methodical choice is concerned with how the research should be undertaken (Saunders et al, 2012). Methodology is an explanation of why certain data is collected, what data is collected, from where the data is collected, when it is collected, how it was collected and how it was analysed (Collis and Hussey, 2003). Therefore, the methodical choice should address four main issues: what data is needed, where the data is located, how data is obtained and how data is analysed?

Saunders et al. (2012) indicated that researchers have six methodical choices to choose from for their research studies; namely, mixed-method complex, mixed-method simple, multi-method qualitative, multi-method quantitative, mano-method qualitative, and mano-method quantitative. The author has opted for a mixed-method simple research which relies mostly on the use of qualitative data collection tools and techniques, but uses quantitative methods as complementary to strengthen the validity and reliability of the research process (*Refer* to Table 4:4). Blaxter et al (1996) stated that research data can be classified as qualitative if it comes in descriptive form, while they are regarded as quantitative if they are in numerical format. The selection of quantitative and qualitative methods depends on the understanding of their application to the research context, which is vital to the success of the research in terms of presenting the phenomenon being studied.

Both quantitative and qualitative methods have strengths and drawbacks. Creswell (2007) referred to quantitative research as an inquiry into a social or human problem, based on testing a hypothesis or a theory composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether the hypothesis or the theory holds true. Creswell (2007) stated that the investigator, primarily uses post-positivist claim for developing knowledge when the quantitative approach is adopted (i.e., cause and effect thinking, reduction to specific variables and hypotheses and questions, use of measurement and observation, and test of the theories), employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistical data. The use of experiments, statistics, content analysis, social survey and structured observation has been identified as quantitative techniques (Bryman, 1998). It has been noted by many authors that quantitative methods ignore social and cultural influences and assume a value-free and objective report (Denzin and Lincoln, 2005). Additionally, it has also been pointed out that a purely statistical logic can make the development of hypotheses a small matter and can fail to help in generating theory from data (Glaser and Strauss, 1967). Based on this shortcoming of the quantitative method, an alternative method of research that is capable of exploring the underlying "real world" environment and to include the hard to define the factors which influence actual human behaviour (qualitative method) is usually proposed.

In contrast, qualitative research involves the studied use and collection of a variety of empirical materials-case study, personal experience, introspective, life story, interview, artefacts, cultural texts and productions, observational, historical, interactional, and visual texts that describe routine and problematic moments and meaning in individuals' lives (Denzin and Lincoln, 2005). Shank (2002) defines qualitative research as "a form of systematic empirical inquiry into meaning". The word "empirical" in this definition implies that inquiry is grounded in the world of experience. According to Walsham (1995), the validity of generalisation in qualitative research does not depend on statistical inference, but on the plausibility and cogency of the logical reasoning used in describing the results from the cases and in drawing conclusions from them. Denzin and Lincoln (2005) argued that qualitative research involves an interpretive and naturalistic approach. This reflects that researchers study things in their natural settings while trying to make sense of them and interpret phenomena in terms of the meaning people bring to them.

After thorough consideration of different method choices, the author concluded that the use of a simple, mixed-method research design was the most viable and the most appropriate. The author's decision is supported by the arguments of Kaplan and Duchon (1988) who maintained that quantitative data can be used as supplementary evidence for an interpretive study and that the adoption of both qualitative and quantitative methods offers a richer contextual basis for interpreting results. Also, Janetzko (2001) argued that the combination of qualitative and qualitative can be complementary; the use of either quantitative or qualitative can have its own advantages and disadvantages. The differences between the two methodologies (quantitative and qualitative) are presented in Table 4:3.

Moreover, the aim of this study is dominantly concerned with an in-depth understanding of the Lean approach in construction project management and particularly with the benefits and implications of Kanban's adoption and implementation. In addition, the concept under investigation (Lean construction and Kanban) is open to a wide variety of interpretations and is context-dependent. Furthermore, investigating the adoption of Lean's Kanban within construction organisations in Saudi Arabia requires the general perception of construction professionals and research to be taken in a natural setting. Therefore, after considering the data collection and data analysis needs of this research, the combination of quantitative and qualitative approach (i.e. mixed method) has been found to be the most suitable.

	QUANTITATIVE RESEARCH	**QUALITATIVE RESEARCH**
Purpose/Objective	To measure various views and options in a chosen sample. Primary purpose is to determine cause and effect relationships. To quantify data and generalise results from a sample to the population of interest.	To provide insight into the settings of a problem. Primary purpose is to describe the ongoing processes. To gain understanding of reasons and motivations.
Setting Hypothesis	Precise hypothesis is stated at the start of the investigation: theories govern the purpose of the investigation in a deductive manner	Hypothesis are developed during investigations: questions govern the purpose of the investigation: theories are developed inductively
Variable Types	The independent variable is controlled and manipulated.	There is no specific independent variable; the concern is to study

		naturally occurring phenomena without interference.
Data Collection Method	Objective collection of data is a requirement. Closed ended questions, questionnaire surveys experiments.	Participant observation, semi-and unstructured interview, focus groups, in-depth discussion and discourse analysis. Objective collection of data is not a requirement; data collectors may interact with the participants.
Research Design	Research design is specified before the start of the investigation.	Research design is flexible and develops throughout the investigation.
Data Analysis	Data are represented and summarized in numerical form.	Data are represented or summarised narrative or verbal form.
Validity and Reliability	Reliability and validity determined through statistical and logical method.	Reliability and validity determined through multiple sources of information (triangulation).
Sample Frame	Samples are selected to represent the population.	Samples are purposefully selected or single cases are studied.
Study Of Behaviour	Study of behaviour is in the natural or artificial setting.	Study of behaviour is in the natural setting.
Statistical Analysis	Use of design or statistical analyses to control for threat to internal validity	Use of logical analyses to control or account for alternative explanation
External Validity	Use of inferential statistical procedures to demonstrate external validity (specifically, population validity	Use of similar cases to determine the generalisability of findings (logical generalisation) of it all
	Rely on research design and data gathering instruments to control procedural bias	Rely on the researcher to come to terms with procedural bias
	Phenomena are broken down or simplified for study	Phenomena are studies holistically, as a complex system
Strength	Reliability of data and findings provide powerful indicators to guide policy. Replicability - publication of questionnaires and dataset permits scrutiny of findings. Transferability of dataset to other analysts means that analysis is not dependent on availability of an individual.	Provides insights into intra-household relations and processes. Provides deeper insights into causes and direction of causal processes. Permits researchers to access data on ‘difficult issues’ e.g. domestic violence. Data on marginal groups that surveys often cannot locate can be collected e.g. illegal migrants, the homeless, child-headed households.

	Precise professional or disciplinary minimum standards exist for much survey work.	
Weakness	Commonly under-reports on marginal/difficult to access individuals and households. Commonly under-reports on marginal/difficult to access individuals and households. Often wasteful in that large amounts of the dataset are never used. Relatively expensive in terms of money.	Completion of research is often dependent on a single individual. Often results cannot be generalised as it is unclear 'whom' they represent. Findings less likely to influence policy as they lack the legitimacy of science and the precision of numbers. Datasets are rarely made publicly available so that findings cannot be tested and other researchers cannot use the datasets.

Table 4: 3 Quantitative vs. Qualitative Methodology
Source adapted from Hulme, (2007)

Methodical Choice	**Description**	**Commentary**	**Decision**
Mono-Method Quantitative	This methodical choice helps researchers to collect and analyse numerical data using systematic techniques such as a questionnaire survey.	This methodical choice is consistent with this research's need to collect data from a large sample of construction workers in Saudi Arabia. The author, also, needs to collect quantitative data using a quantitative survey whose data needed to be analysed and interpreted statistically. Thus, his decision to adopt quantitative research methods is intuitive and is guided by the research's needs.	Partially Adopted
Mono-Method Qualitative	Mono-method qualitative is typically used to collect and analyse text-based data using various techniques such as interviews and focus groups.	This methodical choice is consistent with this research's need to collect data from a group of experienced and knowledgeable construction workers and managers. This research is predominantly qualitative and the author's	Partially Adopted

		main philosophical stance is interpretivism. This makes the use of qualitative research methods very intuitive. Also, the author needed to collect subjective, qualitative data from the employees of the case-study organisation, so he needed to use qualitative data collection methods (i.e. semi-structured interviews) and also use qualitative data analysis techniques; namely, thematic analysis.	
Multi-Method Quantitative	This methodical choice helps researchers to use more than one method or technique for numerical data collection and analysis.	This choice was inconsistent with needs of this study's aim and objectives. The author rejected this choice because he did not need to use more than one quantitative method to guide the collection and the analysis of primary data.	Rejected
Multi-Method Qualitative	This methodical choice helps researchers to use more than one method or technique for text-based data collection and analysis.	This choice was inconsistent with needs of this study's aim and objectives. The author rejected this choice because he did not need to use more than one qualitative method other than the semi-structured interviews to guide the collection and analysis of the primary data.	Rejected
Mixed-Method Simple	This methodical choices is known for its flexibility as it enables researchers to tap the strengths of both quantitative & qualitative data collection tools and techniques	This methodical choice fit very well with this research's data collection and analysis requirements. The author needed to employ both quantitative and qualitative data collection and analysis tools and techniques to be able to achieve this study's aim and objectives. Thus, the adoption of a mixed-method simple research design is intuitive and is guided by the research needs of this study.	Adopted
Mixed-Method Complex	This methodical choice is powerful and robust as it facilitates triangulation and	This methodical choice was far too complicated for this research and would not have allowed the author to collect	Rejected

	enables researchers to make generalisable conclusions.	and analyse the primary data within the short time span allocated for the empirical elements of this research. That's the main reason why the author rejected the use of a mixed method complex research design despite its benefits and advantages.	

Table 4: 4 - Selection of a Research Method

4.7 Research Strategy

A research strategy is a plan or design for conducting a study, through translating the research methodology into specific research methods, the technique used to collect and analyse data (Maylor and Blackmon, 2005). Research strategy dictates the major direction of the research and constitutes one of the important decisions made by the researcher (Pathirage et al, 2008). Yin (2003) refers to research strategy also as research design and describes it as "a logical plan for getting from 'here' to 'there', where 'here' may be defined as the initial set of questions to be answered, and 'there' is some set of conclusions (answers) about these questions". Accordingly, Ghauri and Gronhaug (2005), selection of research design can be considered as the "bridge" between processes associated with the conceptual and empirical levels. Subsequently, researchers have proposed various types for the design of a research. The research design (which can be considered as the structure of the research) is to ensure that the acquired evidences will help the researcher answer all the questions of the research.

Marshall and Rossman (1999) reports that a research strategy consists of the overall rationale, site selection, population selection (or both), the researcher's role, data collection methods, data management, data analysis strategy, trustworthiness features and a management plan. Saunders et al. (2012) indicated that researchers could use one or a combination of eight main strategies to conduct their research; namely, experiment, survey, archival research, grounded theory, case-study, ethnography, action research and narrative inquiry. For this research, the author has decided to use a combination of experiment, survey and case-study as a strategy that governs the data collection and data analysis processes (*Refer* to Table 4:5). There are numerous factors that inclined the author to adopt a combined research strategy. The factors relate to: the nature of the research problem (research questions), the author's personal experiences, accessibility to relevant Saudi construction firms, and accessibility to Saudi construction professionals.

The author had to adopt a case-study strategy because this research is based predominantly on the contextual and operational reality of the Binladin Construction Company. Thus, the author could not have been able to study the company's experience with the adoption of pro-Lean practices in-depth without the use of a case-study research strategy. Also, the author needed to capture the general perceptions of Saudi construction professionals about the most common enablers, barriers, benefits and implications of Lean construction practices' adoption in the context of the Saudi construction industry. The author could not have been able to do so without the use of a web-based survey to collect the necessary primary data about the research subjects in question. Last but not least, the author needed to simulate the impact of Kanban on the time and cost efficiencies of construction operations using the experience of the Binladin Construction Company. Again, this would not have been possible without combining survey and case-study strategies.

Research Strategy	**Description**	**Commentary**	**Decision**
Experiment	This strategy involves the use of manipulation as a scientific process to assess the nature of relationships between two or multiple research variables under controlled or manipulated conditions or circumstances	This strategy has been adopted mainly because it enabled the researcher to simulate the impact of Kanban's adoption of the operational performance of the Binladin Construction Company particularly in relation to cost and time efficiencies. The Discrete Event Simulation process involved the employment of computer software to simulate the impact of Kanban's rules' adoption on performance using Minitab and Simio 10 computer software. This has enabled the author to assess the benefits as well as the implications of Kanban's rules' adoption without causing any form of disruption to the case study firm's operations.	Adopted
Survey	This strategy is commonly used to collect primary data from a specific group of	This strategy is consistent with this research's needs. This strategy has been adopted because it helped the author to collect the	Adopted

	human participants using a list of targeted questions.	required quantitative data from a large group of construction workers who work in Saudi Arabia. The author had to use a survey to study workers' perceptions about the most common enablers, barriers and implications of Lean construction's implementation in the context of Saudi firms.	
Archival Research	This strategy involves the extraction of primary data from existing records.	This strategy is not at all consistent with the needs of this research study. This strategy has been rejected because this research did not require the researcher to collect archival data in order to be able to achieve its aim and objectives.	Rejected
Case Study	This strategy is commonly used to conduct in-depth studies and to investigate the underlying complexities of socially constructed research phenomena.	The author adopted this strategy because it helped him to investigate the contextual circumstances and operational reality of the Binladin Construction Company. This strategy facilitated the study of the case company experience with the adoption of pro-Lean practices in-depth.	Adopted
Ethnography	This strategy involves the study and observation of a group of people in their own, real environments.	This strategy is not at all consistent with the needs of this research. This strategy has been rejected because the author did not need to observe workers in their workplace and the research aim would not have been achieved using ethnography.	Rejected
Action Research	This strategy is a realistic, interactive inquiry process which involves the study of real-life problems and the development of appropriate solutions using problem-	This research strategy was not applicable to the context and nature of this study. The author rejected it because the research's aim did not seek to find a practical solution to real	Rejected

	solving techniques and cross-team collaboration.	live problems or issues and did not require him to work with practitioners to identify and implement practical solutions at the case-study firm.	
Grounded Theory	This strategy facilitates the development of theories or new generalisations through systematic collection and analysis of primary data and using comparative analysis tools and techniques.	This strategy is not at all consistent with the aim and objectives of this research study. This study did not require the author to ground his research in theory or to develop new theory and that's why this particular strategy was rejected.	Rejected
Narrative Inquiry	This strategy facilitates the undertaking of qualitative research studies particularly those which are based on real-life stories. It relies on storytelling techniques and pattern identification tools to study people's shared thoughts and experiences.	This research study is not at all applicable to this research study. This study did not involve narrations of stories by participants; instead it involved the use of semi-structured form of interviews which relied on a pre-prepared list of questions. That's why the author decided to reject this particular strategy.	Rejected

Table 4: 5 - Selection of a Research Strategy

4.7 Time Horizon

Saunders et al. (2012) explained that most research studies can be classified under one of two categories in terms of time horizon namely cross-sectional research and longitudinal research. This research study is cross-sectional because the primary data, particularly the data which was collected using the online survey, was captured at a single point of time. Also, this study does not examine the research subjects in two or more time timeslots.

4.8 Data Collection

Generally speaking, data collection techniques are divided broadly into qualitative and quantitative data collection methods and techniques. The following table illustrates the areas in which qualitative data collection methods differ from quantitative methods:

Area	Qualitative Methods	Quantitative Methods
Data Type	Text/Words	Numerical

Point of Interest	Respondents' Point of View	Researchers' Point of View
Research's Position	Immersed	Isolated
Purpose	New Theory Development	Existing Theory Validation
System	Process/Dynamic	Fixed/Static
Approach	A Fixed Structure	Flexible Structure
Application	Understanding of Meanings	Production of Generalisations
Nature	In-Depth, Contextually-rich	Robust and Reliable Data
Scope	Micro	Macro
Focus	Shared Meanings	Behavioural Outcomes
Implementation	In Real Settings	In Artificial Settings

This research, as in many other research areas, uses both primary and secondary sources of data. According to Cameron (1999), from the primary data, the researcher collects either by direct observation, measurement, interviews, questionnaires or other means which can be modified to his requirement to give answers to exactly the question which concern him, from a suitable sample while the secondary data is a process of reanalysing data that have previously been collected for some intention (Saunders et al, 2009). They are other people's facts and figures, which may be surveyed, carried out by other people; sets of government information such as population census, company report, academic research journal report, etc. The utilisation of secondary data saves time and money, and can be beneficial because part of the background needed for the research has been already surveyed with a pre-established degree of validity and reliability. The researcher can re-use them without the need for re-examining them. However, using the secondary data may not be quite adequate for the research questions because they have been collected for other studies with diverse objectives (Craig and Douglas, 2000) but it can provide a baseline for a research which is about to start and be useful in designing the appropriate methodology by identifying key issues and data collection methods.

A review of available literature can be considered as one of the sources for collecting the secondary data. In this research, books, journal articles, online data sources and documents, and catalogues about construction projects, construction project management, Lean construction processes were included. The selected case study for this research is the Saudi

Arabian construction sector and, therefore, more information about the country, economy and construction projects there had to be reviewed. Therefore, reviewing and analysing these data has been used to contextualise the case study and strengthen the arguments in research by providing credible evidence. This will help the researcher to analyse the collected data from primary sources about the Saudi Arabian construction environment more robust and in-depth.

After due consideration from other studies carried out on the implementation of Lean in construction projects, the selected research method for this research has followed a mixed method approach which involved five stages. These were:

1. A detailed review of academic and practitioner literature to establish the knowledge gap in construction project management and Lean construction.
2. The use of interviews and web-based questionnaires to collect primary data from the employees of Binladin Construction Company / BCC to identify and prioritise the benefits, implications, barriers and critical success factors for the implementation of Lean project management and Kanban's 6 rules of improvement in particular
3. Preliminary analysis to understand the current state of system i.e. to identify the factors affecting the projects and casual relationship between the factors and KPIs.
4. Simulation modelling based on the findings from the literature review, qualitative and quantitative studies which helped guide construction firms on the implementation of Lean project management techniques in order to improve construction performance.
5. To validate the research findings using interviews with project/operations managers of Binladin Construction Company / BCC.

A critical literature review was undertaken during the first phase of this research. Basically to compare the research idea with the existing knowledge, to check the viability of the proposed research (thus avoiding repetition), to learn how to develop an appropriate methodology, to suggest routes for advancing knowledge, and to help in refining the objectives and research questions (Fellows and Liu, 2003). The survey of the literature, specifically for construction project management and Lean construction theory, helped the researcher to understand the requirements, benefits and problems associated with implementing Lean in construction project. This literature consisted of a careful review of textbooks, specialist journals, newspaper publications, and electronic sources, and the secondary data gathered through these means provided the ability to make useful comparisons with the primary data collected during the questionnaire survey. In reviewing the literature, the researcher focused on Lean's tools, techniques and principles in construction project management and on Kanban's six rules of improvement in particular, this being precisely pertinent to the aim of the study.

The primary data were mainly collected using interviews and a web-based questionnaire survey. The interviews followed a semi-structured approach to the data collection process. A small number of pre-defined research questions were prepared prior to the interviews taking place, but a lot more questions were asked during the interviews. This way the author was able to collect the right amount and type of data he needed to achieve the research's aim and objectives. The questionnaire survey was designed using samples from previous studies. All of the questions were simple, brief and used multiple-choice form of questioning. This study also collected and used historical data i.e. any information on past projects with construction professionals in Saudi Arabia. This approach identified the benefits, implications, barriers and implementation enablers of Lean construction's tools and techniques particularly Kanban.

4.8.1 Sampling Approach

Sampling is the means whereby the researcher is able to decrease the total data needed to be collected by taking into consideration only data from a subgroup instead of all likely cases or element (Saunders et al, 2009). This can be illustrated in Figure 4.5.

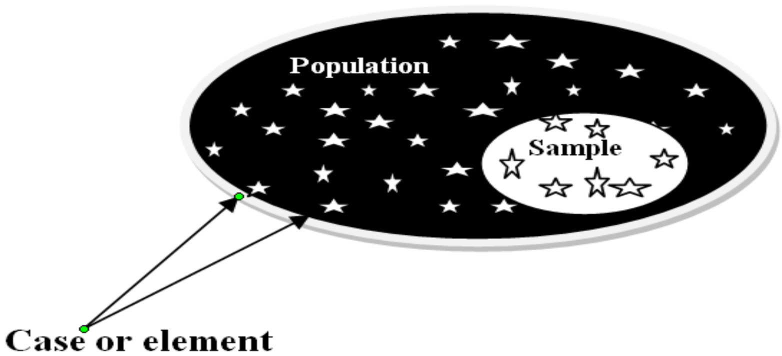

Figure 4: 4 - Population, samples and Individual cases
Source: Saunders et al. (2009)

According to Saunders et al (2009), the techniques for sampling are available in two types:

1. Probability (random) or representative sampling- This is the process where the case that is collected from the population is recognised and is more often than not equivalent for all cases i.e. It is probable to answer the research query and to attain

the purpose that need the researcher to evaluate statistically the description of the population of the sample (Saunders et al, 2009). This kind of technique is associated with the survey and experimental research strategy. The process of representative sampling is divided into 4 stages;

I. Identifying an appropriate sampling structure based on the research question or objectives.
II. Make a decision on a suitable sample size.
III. Select mainly appropriate sampling technique and decide the sample.
IV. Ensure that the sample is representative of the population.

Consequently, Saunders et al (2009) states, five types of probability sampling, which are simple random, systematic, multi-stage, stratified random and cluster sampling.

2. Non probability (selected) or judgemental sampling- this is a method where every case being selected from the whole population is not recognised and it is not possible to answer research questions or tackle the purpose that need the researcher to produce a statistical conclusion concerning the characterises of the population. This technique is essential because it gives a variety of options to select samples based on subjective decision. The common types of non-probability sampling, are convenience samples, purposive sampling, snowball sampling, and quota samples.

The target sample in this study is Binladin Construction Company's workers and managers. They are deemed the most appropriate target for any research seeking to apply scientific management techniques in construction project management.

4.8.2 Simulation and Modelling

This research involved the use of simulation software to evaluate the impact of Lean's tools' adoption on the performance of Saudi construction firms. The application of modelling and simulation techniques in solving construction project management concerns has been reported by Smith et al (2006). Modelling and simulation may be described as the process of investigating the behaviour of a system in a simulated environment. The process may involve describing a system mathematically, while taking into consideration system variables and constraints. In the course of this research, the simulation modelling involves the development of discrete event simulation model based on the data collected in assessing the implementation efforts of Lean project management. Minitab and Simio 10 simulation software has been used to simulate Kanban's adoption's impact on the operational performance of the case study company.

4.9 Design of Experiments

This research used the Taguchi technique for Design of Experiments (DoE) to design and simulate the impact of Kanban's adoption of the operational performance of the case-study firm. The history of DoE goes back to the early 1900s when RA Fisher considered the use of specialist, scientific techniques to design experiments that mirror the real-world conditions. In the mid 1990s, a new technique emerged in the Toyota factor in Japan that advanced the process of designing realistic experiments which mimic real-life operational contexts. This technique is named after its developer; namely, Genichi Taguchi. The Taguchi technique has six steps as shown in Figure 4:5. These steps have enabled the author to use multiple scenarios and incorporate several variables in experiments that accurately mirror the current state of Binladin Construction Company's operations and also identify new ways of improving the firm's performance and addressing the root causes of delays and cost overruns.

- ❖ Step 1: Select the Response Variable.

The first step in the Taguchi technique is to identify the relevant variables which the designer is trying to measure their impact or interdependence in relation to other variables. This study has examined the impact of workers' numbers, workers' cost per day, processing time, setup time and suppliers' delay on the time and cost efficiencies of the case-study firm's framing, windows, elevators, electrical, drywall and exterior casework construction activities.

- ❖ Step 2: Define Parameters and Levels

This step requires designers to handpick parameters and define the levels of variation levels. In this study, the factors comprised: workers' numbers, workers' cost per day, processing time, setup time and suppliers' delay. The impact of these factors on the dependent variables was assumed at three different levels; namely, low, average and high. For example, the cost of workers per day of the 'framing activity' was estimated to be as low as 200 SR and as high as 300 SR. The average value was set at 250 SR.

- ❖ Step 3: Select the Orthogonal Array

In the third step, designers select appropriate orthogonal arrays (QA's) as shown in Table 4:6. It is a process of identifying optimal orthogonal arrays of the variables that have an influence on the main research constructs (i.e. the time and cost efficiencies of construction activities). In this research, the Taguchi tables comprised five variables and three factors.

The variables are: workers' cost per day, processing time, setup time, workers' numbers, and supplier delays. Each of these variables has three levels of estimates. For example, suppliers' delays for the exterior casework activity are estimated to range from 7 (low) and 10 (average) to 14 (high).

❖ Step 4: Perform the Experiments

In the fourth step, designers conduct experiments and produce results which can be examined and interpreted to identify the optimal operating parameters or conditions.

❖ Step 4: Analyse and Determine Optimum Parameters

In the fifth step, designers examine the variables or factors that have an impact on the process under study and identify optimum parameters which can help them to optimise the process in question. The idea is to explore how a change in any of the parameters can lead to a positive change in the outcomes or in the dependent variables.

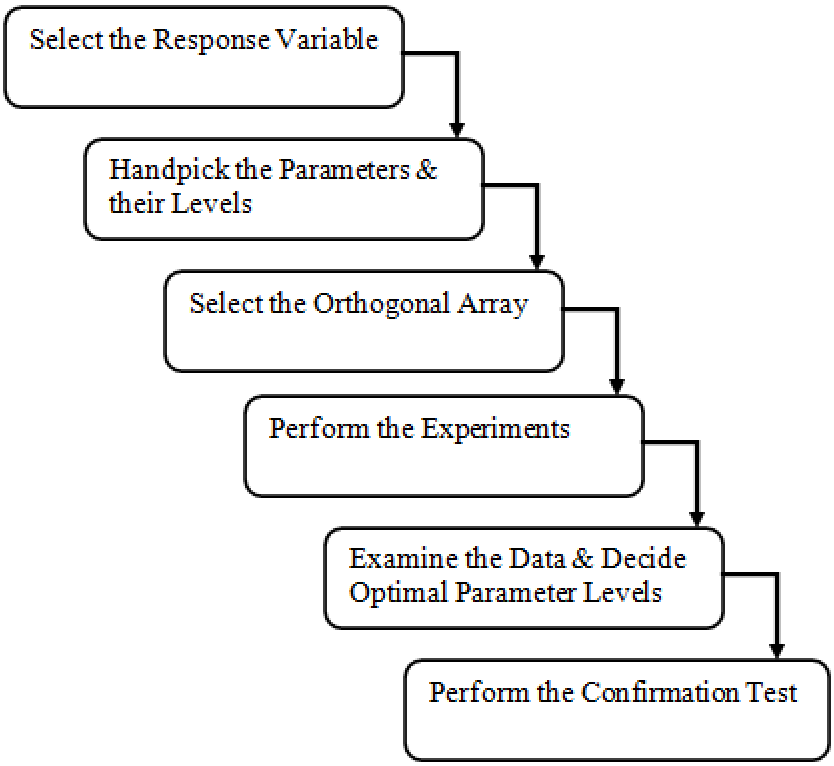

Figure 4: 5 - Flow Chart of Taguchi Method Steps
Derived from: Mousavi et al. (2019)

❖ Step 6: Predict Optimum Performance

In the fifth step, the designer anticipates or predicts the performance of the process with the conditions or parameters identified in the previous step. The idea is to facilitate and support the optimisation of the process in question.

❖ Step 7: Confirm Experiment Design

In the seventh and final step, the designer validates the final experiment design using the identified 'optimal parameters' in order to achieve the desired performance target. In this research, 54 real-world scenarios have been used to predict the impact of Kanban's rule's adoption on the time and cost efficiencies of the construction activities under study; namely, framing, windows, drywall, exterior casework, elevators and electric.

Orthogonal Array	No. Runs	Max. Factors	Max. of columns at these levels			
			2-level	3-level	4-level	5-level
L4	4	3	3			
L8	8	7	7			
L9	9	4		4		
L12	12	11	11			
L16	16	15	15			
L'16	16	5			5	
L18	18	8	1	7		
L25	25	6				6
L27	27	13		13		
L32	32	31	31			
L'32	32	10	1		9	
L36	36	23	11	12		
L'36	36	16	3	13		
L50	50	12	1			11
L54	54	26	1	25		
L64	64	63	63			
L'64	64	21			21	
L81	81	40		40		

Table 4: 6 - Taguchi's Orthogonal Array (Source: Lan and Wang, 2009)

4.10 Modelling of Kanban's Impact Using DES

This research involved the use of Discrete Event Simulation (DES) to simulate the impact of Kanban's rule's adoption of the operational performance of the case-study firm. Simulation is typically used by researchers to mirror real-life conditions and circumstances to assess the outcomes or outputs of processes or operations. In other words, simulation allows researchers to experiment with and explore the relationships or reactions of different variables without causing a disruption to real-world processes or operations which they are trying to mirror. The purpose of DES in this research is to assess the impact of several independent variables on a set of dependent variables in the operational context of six main construction activities. The independent variables are: workers' cost per day, number of workers, processing time, setup time and suppliers' delays. The dependent variables are the cost and time it takes for construction workers to complete: framing, windows, elevators, drywall, exterior casework and electrical construction activities.

The six activities this research is studying are critical components in a much larger process. The process starts with an initiation process which takes around 10 days to complete. Then, the relevant stakeholders begin to jointly develop a management plan for the entire lifecycle of the construction project. This activity involves the development of initial plans for time and cost management. It also involves agreements about the resources needed to achieve a project's goals and identification of roles and responsibilities for all stakeholders. It takes around 15 days for the management team to develop provisional plans and time schedules. In the next step, managers thoroughly review all relevant plans and make an informed decision about whether to proceed to the next phase or go back to the drawing board. This is a critical activity which is concerned with reviewing the initial plans for time and cost management. In this activity plans are presented to senior managers, advisers and experts for scrutiny so that a decision for amendments or approval is made. It also involves decisions about the approval of key suppliers and contractors. It takes construction firms around 35 days to set budgets, agree time schedules and select good suppliers.

In some projects' life cycles, there is a 'demolition' phase. For the purpose of simulation, the author assumed that the demolition was a critical activity and that the simulated project couldn't progress unless this activity is completed successfully. This activity is concerned with tearing down old buildings or structures to make way for the project under construction. It typically takes around 73 days for demolition of average-sized buildings to be completed. The next activity construction activity the simulation model considered to be 'excavation'. This activity usually takes around 33 days on average construction projects. It involves the movement of soil, rocks and other materials. This activity is critical for almost all construction projects due to the fact that firms can't build up structures or frames without making sure that the area is excavated and readied the project. It usually precedes the 'concrete' activity. Concrete has been yet another critical activity which involves the use of composite materials to build and/or support the structural foundations of a construction project. This particular activity often takes firms around 29 days to complete.

This research also considered 'backfilling' when drawing the process map of the construction project under investigation. Backfilling involves putting the soil back onto the foundations of a construction project once the 'concrete process' is over. This activity is closely linked to, and interdependent on the 'excavation' activity. It takes around 48 days for construction workers to complete this activity, on average. It usually precedes the 'framing' activity. Framing is one of the six core activities this research investigates. This activity is very important. It involves putting together the structural architecture of a construction project. It requires firms to put together frames, which can be in the form of wood, steel or concrete to give structure the necessary shape and support. This activity can take as long as 42 days to be completed. Its process is conceptualised to flow parallel to the 'plumbing' activity which involves putting together systems of pipes and fixtures which facilitate the transfer of water (mostly drinking water) in the building as well as support the removal of waterborne wastes. It takes plumbers around 43 days to finish this activity.

Another activity that this research considered to study is electrical fixtures' installations. This is concerned with installing anything that may be classified under 'electric supplies' such as lightings, elevators, HVAC, etc. It involves the wiring and assembly of electrical systems. It takes construction workers around 41 to complete this activity. The installation of 'elevators' was also studied as one of the six core construction activities. In the process map, it precedes the 'drywall' activity. Installation of drywalls is equally important and was also considered as part of the six core construction activities. This activity is concerned with the application of drywalls onto the interiors of buildings. Almost all building construction projects require the use of some form of drywall construction. It takes construction workers around 24 days to finish all drywall activities and proceed to the exterior stone and interior casework activities.

The last two activities the researcher considered as part of process map of the construction project under investigation were: finalisation of the project and sustainability certification. The earlier activity signals the completion of a construction project. It involves thorough inspects and reviews of the constructed facilities, particularly in terms of quality of finished structures and their compliance with pre-agreed specifications. The latter activity involves applying for, and acquisition of relevant certificates to confirm the sustainability of the constructed facility, structure or building. It takes approximately 15 days for sustainability to be assessed and for certificates to be issued.

4.11 Validation of Research Propositions

The main proposition of this research is that the adoption of Lean management systems in general and Kanban's six roles of management in particular help Saudi construction firms to improve their performances and address the issues of delays and cost overruns. To validate this proposition and understand the advantages and implications of Lean in the context of Saudi construction firms, the researcher used three techniques; namely, interviews, web-based survey and simulation software. The validation process involved two stages. In the first stage, the researcher collected primary data from the employees of Binladin Construction Company using semi-structured interviews and a questionnaire; and in the second stage the researcher used Simio 10 software to simulate Kanban's improvement potential (*See* Figure 4:6).

4.11.1 Validation - 1st Stage

The first stage of validation involved the collection of both primary and secondary data. The secondary data was collected from the case study company's archives and also from peer-reviewed journal articles. The idea was to develop a good understanding of the case study company's performance issues and what had been done to address them prior to starting the collection of primary data. The researcher needed to understand the problems very well so that they could collect primary data that's relevant and which would help the researcher to examine how Lean tools and techniques might help the case study company to address the root causes of inefficiencies. The researcher also needed to review relevant academic publications in order to understand the experiences of other construction firms in relation to the use and efficacy of traditional project management practices and the adoption of advanced project management. The review enabled the researcher to identify the most common benefits, enablers and barriers of Lean construction which were then used to come up with relevant and specific questions and statements for the survey and interview questionnaires.

The researcher needed to pre-test the research propositions and arguments which revolved around the assumption that Lean management's tools and techniques would be of great benefit to Saudi construction firms. Basically, the researcher thought it was essential to gauge the perceptions and opinions of the case study company's employees of Lean construction especially in relation to traditional project management practices. To do this, the researcher used both interviews and an online survey. The purpose of the survey was to identify the factors that hinder the abilities of Saudi construction firms to achieve optimal operational performance and also explore the benefits, barriers and enablers of Lean construction in general, and Kanban in particular. On the other hand, the researcher used semi-structured interviews to deepen the understanding of the operational challenges or problems that Saudi construction firms had been dealing with especially those related to cost and delays. The data from the interviews also enabled the researcher to evaluate and scrutinise the efficacy of traditional project management tools and techniques especially in terms of helping construction companies to reduce costs and prevent unnecessary delays.

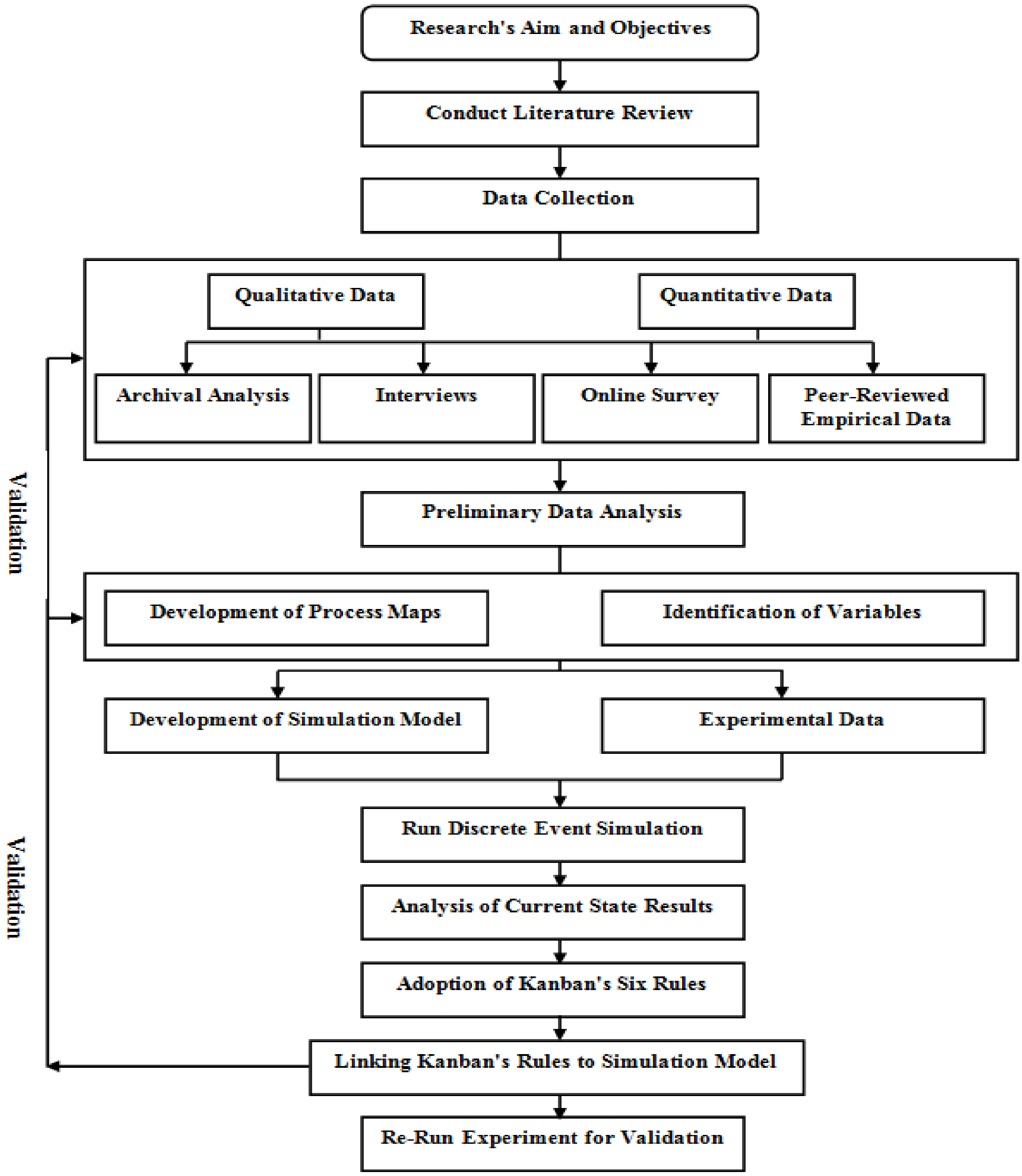

Figure 4: 6 - Flowchart of Research Methodology's Steps

The interviews' participants were selected carefully using pre-defined selection criteria. For example, all the interviewees had to have good understanding of Lean construction and contemporary project management practices. They needed to be aware of Lean construction's tools and techniques as well as current project management practices in order for their feedback to be useful for the assessment of the research findings. The participants also had to be directly involved in the implementation process of Lean in their company. This criterion ensured that all of the participants had knowledge of Lean implementation benefits, enablers and challenges which I needed to understand.

The outputs from the primary and secondary data analyses in the first stage of validation set the scene for the second stage and provided the foundation for succeeding research processes; namely, design of experiments (DoE) and discrete event simulation (DES). The quantitative data also provided a definitive insight into the most common enablers, barriers, benefits and implications of Lean construction systems' adoption, particularly in relation to the implementation of Kanban's six rules of improvement. The qualitative data, on the other hand, allowed the researcher to develop a contextually rich understanding of the current operational problems faced by the case study company and how Lean tools and techniques had helped to improve its operational efficiency. The interviews also has been an eye opener on the limitations of traditional project management systems and practices and the challenges associated with the adoption of more advanced management systems.

4.11.2 Validation - 2nd Stage

The results from the first stage of validation confirmed the research propositions and the author's conceptual arguments especially in relation to the efficacy of traditional project management practices and the perceived benefits of Lean management's practices, tools and techniques (*See* Chapter 5, sections 5.2 and 5.3). The preliminary results also facilitated the development of process maps and identification of key variables which were essential for building the simulation model and conducting the experiments. The results from the interviews in particular had been used to support the development of the desired discrete event simulation model. This was in addition to project/operations managers' personal inputs to the estimates of how long it usually took to complete each of the activities under investigation. It was necessary to develop a simulation model that mirrored real-world conditions as closely and accurately as possible so that the researcher could assess the potential impact of Kanban's adoption on the operational efficiency of the construction activities in question. The discrete event simulation model enabled me to assess the state of operational performance of the case-study company before and after the adoption and operationalisation of Kanban's six rules of improvement. This helped to identify the areas that required the managers' attention.

The development of the discrete event simulation model required the researcher to; identify all the relevant activities; seek the assistance of managers from the Binladin Construction Company with the time and cost estimations for each construction activity; and draw up a flow chart for critical activities. These were necessary for me to be able to draw up a process map for the construction scenario under study and identify all the relevant variables which needed to be incorporated into the design of experiments and then into the discrete event simulation model. The process map was validated and confirmed by experienced project and operations managers from the case-study firm (*See* Figure 5:1).

The researcher would not have been able to develop a realistic simulation model without a validated process map. This was critically important and needed the map to create a Simio process that closely and accurately mirrored real-world conditions and control variables. Also, the Simio 10 software enabled the researcher to examine how changes in independent variables affect the dependent variables (i.e. the time and cost of construction activities).

The process map and the simulation model were both needed to design the simulation experiments. The researcher adapted Taguchi's design of experiments technique to do this. It enabled the researcher to decide on the number of experiments that's adequate enough to assess the current state of Binladin Construction Company's operational performance and also to predict the potential impact of Kanban's six rules of management on the time and cost efficiencies of the firm in each of the six construction activities under investigation.

The development of the simulation model and the design of experiments set the scene for discrete event simulation (DES) which allowed the researcher to build scenarios that closely resembled the real-life operational context of the Binladin Construction Company and mirrored the environment in which the company operated and conducted its activities. The researcher adapted the Simio 10 software to simulate 54 scenarios for before and after the adoption of Kanban's operational principles. Also used ANOVA to gauge the correlations between the different variables in the experiments for both, the current state and improved state. ANOVA is a popular data analysis tool as it provides researchers with the necessary statistical tools, procedures and techniques they need to assess the interconnectedness and the significance of correlations which exist between a set of independent variables and dependent variables. The P-values produced by ANOVA allowed the researcher to identify which variables had statistically significant impact on the time and cost efficiencies of the activities and the ones which didn't have as strong correlations.

4.12 Ethical Consideration

In the context of research, ethics refers to the suitability of the behaviour of the researcher in relation to the rights of those who become the subject of the work or are influenced by it. Cooper and Schindler (2008) define ethics as the "norms or standards of behaviour that guide moral choices about researchers' behaviour and relationships with others". Ethical principles have been applied in this thesis in order to prevent ethical issues, because people were involved in questionnaires and interviews and the researchers' behaviour with them was important. Participants were assured that their information is kept confidential, they have the right to withdraw at any time and everything is with their consent, there is no deception and they were informed about every single step. Ethics application has also been approved by De Montfort University, Leicester before the start of actual data collection.

4.13 Chapter Summary

This chapter presented the research process adopted and the rationale for using both quantitative and qualitative methodologies. The choice of both approaches was justified by the nature of the study investigation and the method deemed fit for the research questions. The qualitative methodology mostly describes phenomena using words while the quantitative methodology measures them and describe results numerically. The research uses a pool of information/data from multi-sources, which provides it with the right levels of reliability and robustness. It also uses simulation software to assess the impact of Kanban's adoption of the operational performance of the Binladin Construction Company. Table 4:7 summarises the overall research design.

Category	**Choices**
Research Philosophy	Hybrid Philosophy (Interpretivism Complemented by Positivism).
Research Approach	Abduction (Induction Combined with Deduction).
Methodical Choice	Mixed-Method Simple (Qualitative Research Complemented by Quantitative Research Methods.
Research Strategy	A Combination of Case-Study and Survey
Time Horizon	Cross-Sectional Research

Data Collection Methods / Techniques	A Combination of Semi-Structured Interviews, Online Survey and Direct Input from Professionals (for Simulation Data)
Data Analysis Tools / Techniques	Thematic Analysis for Text-Based Data, Statistical Analysis for Numerical Data and Discrete Event Simulation for Experiments.

Table 4: 7 Chosen Research Design

Chapter 5: Data Analysis & Interpretation

5.1 Introduction

This chapter presents the outputs of data analysis and interpretation processes for the primary data which has been collected using interviews and questionnaires. It starts with the data from the interviews. It presents, interprets and discusses key interviewees' most important statements. The second part of this chapter analyses and discusses the results of the quantitative questionnaire. The questionnaire's data have been analysed statistically and is discussed in light of other studies. This chapter ends with a summary of the findings.

5.2 Findings from Interviews

In order to achieve this research's aim and objectives, the author has conducted interviews with employees of Binladin Construction Company / BCC. He used a semi-structured form of interviewing to extract relevant data from the participants who held a variety of jobs in the case-study company (*Refer* to Appendix II for interview questions). The interviewees included designers, engineers, architects, estimators and most importantly, project managers. Although the author attempted to interview at least 15 employees from Binladin Construction Company, he had only been able to secure interviews with 10 people who hold different jobs and who have different roles and responsibilities, namely:

1. Construction Project Designer 1 - **CPD-1**
2. Construction Project Designer 2 - **CPD-2**
3. Construction Project Engineer 1 - **CPE-1**
4. Construction Project Engineer 2 - **CPE-2**
5. Project Architect 1- **PA-1**
6. Project Architect 2- **PA-2**
7. Project Estimator - **PE**
8. Construction Project Manager - **CPM**
9. Operations Project Manager - **OPM**
10. Assistant Project Manager - **APM**

The ten participants provided the author with just enough primary data to satisfy his research's needs. They weren't selected randomly. Instead, each of the participants was targeted specifically for his/her knowledge, experience and the nature of their day-to-day duties and responsibilities. For example, several participants had very good knowledge and understanding of project planning, design, budgeting, costing, quality control and most importantly what it means to have efficient operations and effective management.

The following table shows the list of questions the author has asked in the semi-structured interviews and the number of participants who responded to each of the 21 questions:

Question	Response Rate
1. Tell me a bit about your job - your roles and responsibilities?	All of the participants (100%) responded to this particular question.
2. What are the operational challenges your company has been dealing with?	Only six out of the ten participants (i.e. 60%) provided a meaningful answer to this question
3. What are the issues that are affecting your company's operational performance?	Eight out of the ten participants (i.e. 80%) provided a meaningful answer to this question
4. How often do projects in your company go over-time or over-budget?	Only six out of the ten participants (i.e. 60%) provided a meaningful answer to this question
5. What do you know about Lean construction? Is it transferable to Saudi firms?	All of the participants (100%) responded to these two questions.
6. How could Lean construction practices help deal with time and cost overruns?	Eight out of the ten participants (i.e. 80%) provided a meaningful answer to this question
7. How effective are traditional project management practices, tools and techniques in terms of dealing with the challenge of time and cost overruns in particular? What are their drawbacks in terms of dealing with today's construction challenges?	Seven out of the ten participants (i.e. 70%) provided meaningful answers to this set of questions.
8. What project planning and control methods do you use to plan construction activities and control your company's operational capacity? What other methods besides CPM (critical path method) do usually use for planning and control of activities?	Only six out of the ten participants (i.e. 60%) provided meaningful answers to this set of questions.
9. Who gets involved in the development of project plans and schedules?	All of the participants (100%) responded to this particular question.
10. What are the things or issues that cause time and cost overruns in your company?	All of the participants (100%) responded to this particular question.
11. Do you think your company is doing enough to optimise its planning and control?	All of the participants (100%) responded to this particular question.
12. How often project schedules were revised or modified by project planners?	Just three out of the ten participants (i.e. 30%) provided a meaningful answer to this question

13. How do you think your company should improve its planning performance?	Just five out of the ten participants (i.e. 50%) provided a meaningful answer to this question
14. What do you think about Lean tools and techniques? Do they add any real value to your company's pursuit of optimal operational performance? What are their pros and cons in the context of your organisation?	All of the participants (100%) responded to these questions.
15. What are the factors or contributors that encouraged your company to adopt the tools and techniques of Lean construction? Do managers actually support the adoption and use of modern project management tools and practices like Lean Construction's?	All of the participants (100%) responded to these questions.
16. What are the benefits that your company has gained from the implementation of pro-Lean tools, techniques and practices? What do you think of Lean techniques like Heijunka (Level Scheduling); LPS; Kanban (Workflow Management); 5S; and Kaizen.	All of the participants (100%) responded to these questions.
17. What are the factors which have enabled or facilitated the implementation of pro-Lean tools, techniques and systems in your organisation? Do workers and managers have favourable attitudes toward the adoption of pro-Lean initiatives? Do you think the human and behavioural factors play an important role? How about other hard factors like the management systems and structures? Do you think the use of consultants is important and helps with the implementation?	All of the participants (100%) responded to these questions.
18. What are the factors which have hindered or obstructed the implementation of Lean construction tools, techniques and systems in your company?	All of the participants (100%) responded to this particular question.
19. Do you think the cost of implementation of pro-Lean initiatives a major barrier? How about the investment commitment required for Lean adoption, is it a major barrier?	Just three out of the ten participants (i.e. 30%) provided a meaningful answer to this question
20. What do you think your company should do to minimise the barriers and maximise the enablers of pro-Lean initiatives?	All of the participants (100) put forth ideas and suggestions, but not all of them were meaningful or viable.
21. Would you like to add anything else?	Only 3 participants (30%) provided further statements about Lean construction practices.

The raw data from the interviews was organised and analysed using 'thematic analysis'. The analysis and interpretation processes comprised six key steps. Firstly, the author began by familiarising himself with the different statements made by the participants. The idea was to get an understanding and general idea of the raw data so that the author could know how it should be organised and prepared for the next step. Secondly, the author coded the different 'key' and 'important' sentences and phrases that share the same meaning or offer similar thoughts or ideas by giving these phrases or sentences codes or shorthand labels. For example, when a participant states that their organisation still uses the "the old paper-based tools to plan schedules" or "unfortunately we have not been able to streamline our operations due to lack of technologies that facilitate real-time sharing of information", both statements are coded under the label of 'ineffective planning operations'. Thirdly, sentences and phrases that shared the same codes were grouped together. The author then began looking for patterns and started dividing and organising the text under common banners or themes. There were times when different codes and their associated statements were combined together and put under a single theme.

Fourthly, the author reviewed all of the identified themes, to ensure that they were accurate reflections of participants' opinions and that they were useful for this research. Basically, this step involved a critical review and evaluation of the author's approach to coding and identification of themes so that if there was anything missing from the codes, themes or sub-themes, it could be identified and incorporated into the identified themes. Fifthly, the defined and named the identified themes based on their contents and main arguments. This step involved the formulation of definitive and precise titles for the identified themes allow the author as well as readers to recognise the overarching argument or claim which dominate individual themes. Lastly, the author initiated the writing up process by going through each individual theme and discussing its core ideas and arguments in light of this research's aim, objectives and research questions. This step also involved identifying and presenting important quotes which reflect the participants' general perceptions or opinions.

Thematic analysis of the data enabled the author to identify seven important themes; namely, (1) operational challenges and Lean construction; (2) efficacy of traditional project management; (3) project planning and control methods; (4) perception of Lean construction; (5) drivers and benefits of Lean construction; (6) enablers and facilitators of Lean construction; and (7) barriers and challenges of Lean construction' implementation.

5.2.1 Theme A: Operational Challenges and Lean Construction

The interviews discussed the case-study firm's operational challenges, especially those related to cost and time overruns and how Lean construction could help it overcome them. First of all, two out of the ten participants (20%) claimed that their firm's operational performance would improve significantly if managers abandoned the use of "paper-based tools" in favour of real-time planning and control techniques such as Lean's Andon. Andon is a real-time communication tool which acts as 'visual feedback system' to alert shopfloor managers about problems so that they could be addressed immediately. Lack of real-time feedback has, for so long, hindered the firm's ability to achieve optimal performance. The way feedback is provided can only be characterised as 'unsystematic' and 'sporadic'.

Secondly, one of the participants claimed that their firm's operational performance would continue to deteriorate unless it further improves and optimises its planning operations. He suggested that the firm should: (1) make greater use of process simulations; (2) synchronise production, engineering and on-site installation operations; (3) digitise information sharing and feedback processes; (4) improve operational transparency through real-time data sharing; and (5) make sure all key stakeholders are involved in the entire planning process. At the moment, the firm still follows conventional three-phased approach to project management: design, plan and execute. Usually in the design phase practitioners, designers and architects establish a design concept for a project and set out its technical specifications. It then goes to the planning stage where key stakeholders (e.g. site supervisors, project managers) conduct what's known as "organisational execution planning". They specify time schedules and consider the financial, physical and human resources needed to achieve the project. After detailed plans are developed, the project moves to the execution stage. The problem with this approach is that teams work in isolation and crucial processes are disconnected. It also fails to appreciate the interdependent nature of the different phases of construction projects. On the contrary, Lean construction puts great emphasis on the use of cross-functional teams and on cross-departmental collaboration. It also stresses strongly on the involvement of all important stakeholders in all phases of construction, particularly in the planning phase.

5.2.2 Theme B: Efficacy of Traditional Project Management

The interviews explored the participants' perceptions of traditional project management tools and techniques and their effectiveness relative to Lean's. It was found that traditional methods and practices provided construction firms with good means of controlling costs and reducing the risk of delays, but they hadn't been effective in dealing with contemporary operational challenges of the construction industry. Contemporary mega-projects are characterised by unprecedented levels of complexity and dynamism which make project managers' efforts to complete them on time and on budget very challenging. Four out of the ten participants (40%) confirmed that their traditional management methods had failed to facilitate optimal performance, especially in relation to the management of time and cost. For example, a participant stated:

> "You need to think of it this way - schedule and cost overruns are part of our reality. Did you know that almost eight out of ten of our large project experience delays and cost more than planned? What I am saying is that just about 20% of large projects that take between 3 and 5 years to complete are usually delivered in time and on budget" - **APM**.

This statement highlights the shortcomings of traditional project management practices. They don't seem to have the efficacy to account for all of the problems and risks which undermine construction firms' abilities to stay on schedule and on budget. What makes this problematic is that Saudi project managers accept time and cost overruns as part of their reality and don't appear to have the urge to take big, decisive steps to address the root causes of the problem. Moreover, although the case-study firm has adopted a number of important Lean construction practices, its managers were found to have a tendency to use traditional tools and techniques which provide a simpler means of planning and control. Undoubtedly, the company's senior management is frustrated with traditional project management practices because time and cost overruns are not only costly for project owners, but also for construction firms. Non-excusable delays usually carry financial penalties which require contractors to compensate project owners for prolongations. In other words, it is for the benefits of both, contractors and project owners for projects to be completed on time and on budget. So, why Saudi firms have not acted urgently enough to embrace Lean project management systems?

There were indications in the interviews that numerous engineers and managers had voiced their concerns about the use of outdated management tools and techniques to plan and control the operations of mega-projects. One participant said that there had been "calls from different experienced engineers and planners for reform and change of our planning procedures. Sadly, their calls haven't been taken seriously enough and management continues to use in-house planning systems. There have been minor changes, though particularly in terms of how we work with other teams and how supply chain operations are managed" - **CPE-2**. This statement could mean that the case-study firm doesn't reject the idea of transitioning to contemporary management the likes of Lean construction altogether, but refuses to make a dramatic and revolutionary shift away from traditional practices as that could disrupt its current operations.

5.2.3 Theme C: Project Planning and Control Methods

The participants were asked about the planning and control tools and methods they used to plan projects and to ensure work is completed in line with the schedule. Six out of the ten participants (60%) indicated that management relies heavily on the critical path method or CPM. They also stated that project managers had been using Oracle's Primavera software to plan and schedule jobs. Three out of the ten participants (30%) indicated that the firm had been using both CPM and PERT charts to plan and schedule project's tasks. One participant claimed that "CPM is used a lot not only by our company, but also by other good construction firms. It is popular because it simplifies the planning process and helps us to identify the tasks we should focus on in order to avoid delays and to complete all tasks within schedule" - **OPM**. This claim is quite true especially in relation to the popularity of CPM and PERT among project managers, but good construction firms use more advanced planning software and processes than CPM.

The participants also discussed the planning challenges and how project managers found it hard to keep projects on schedule despite paying due consideration to all possible causes of delays. One participant explained that project managers were doing their best to avoid delays, but changes to project scope, budget or design often made it difficult to stay on schedule. Design-related issues received greater attention from the participants than other issues. They argued that poor design quality, incomplete design drawings and redesign requests were often the main causes of disputes and project work interruptions. The assistant project manager claimed:

> "I personally have witnessed and experienced the operational implications of having a bad design team, which fails to provide complete specifications and produces poor quality design drawings. There was this one time when the designers were supposed to design a 6-meter access chamber opening for maintenance, water pipe, but due to their incompetence, they drew a 4-meter opening in the design. When the issue was

> discovered, the designers were reluctant to take responsibility and merely said that it was fixable and that the operations team can easily resolve it" - **APM**.

This statement highlights the importance of hiring qualified and experienced designers for the design and planning of major construction projects. Failure to do so would only lead to more unnecessary delays and increase the risk of schedule and cost overruns. It is typical of project owners to have full confidence in their designers, to believe that they wouldn't produce poor quality, incomplete documents and to assume that they would comply with all relevant codes, standards and industrial best practices. However, this isn't always the case. Even the most reputable designers might fail to produce good quality designs that don't leave out important information and comply with all operational and constructability requirements. In fact, more often than not, construction project design documents are produced and issued prematurely and that complicates the planning process and increases the risk of time and cost overruns.

Moreover, the statement also highlights the potential implications of poor communication between the clients and designers. One could argue that it is not the fault of designers to produce incomplete or incoherent designs when clients or project owners fail to provide them with all the relevant information and specifications. A breakdown in communication between the two parts could lead to problems similar to the one highlighted in the above statement. Thus, the importance of clear communication can't be overemphasised.

Two out of the ten participants (20%) also raised concerns about the time at which project schedules are produced. They claimed that it was common in Saudi Arabia for project owners to demand a Master Schedule within 28 days from the date of commencement. It was argued that the time wasn't long enough for project managers to fully understand the requirements of the project and to device realistic schedules. One participant stated:

> "[...] we don't always get enough time to get our heads to understand a project's scope and we are often rushed to provide rough plans without considering all the factors and issues which could cause delay or significant disruptions. To be honest, even when we get sufficient time, our plans never turn out to be perfect. There are always differences between what we plan and what actually happens on the ground later on [...]" - **CPM**.

The interviewees were also asked about who usually participated in the development of plans and schedules. Their responses suggest that a variety of stakeholders are involved in different stages of the planning process. Planning consultants and specialists were said to be involved in the bidding stage during which draft, initial plans is developed to support a bid for a new project. Construction managers and project managers are more often involved in developing the Master Schedule once a project is won. Project and construction managers tend to have a greater feel of the operational implications of plans than consultants, so their inputs are often valued greatly. Other important stakeholders include, but not limited to; project owners, site engineers, supervisors, designers, suppliers and sub-contractors. Sub-contractors are typically involved in the final, pre-construction stage of the planning process.

Moreover, the participants were encouraged to talk about how often project schedules were revised or modified by project planners. There were shared opinions among the interviewees that baseline schedules were typically updated several times as projects progressed. The operations manager explained:

> "It is very common for our project schedules to be updated on a frequent basis. The updates reflect a variety of things such as unforeseen problems, time extensions or natural disrupters like stand storms and floods. There are things that we can't plan for and when they happen, they disrupt our operations. So our schedules must be updated accordingly. What I am trying to say here is that schedule revisions aren't a bad thing and don't mean that we are doing a terrible job in terms of meeting our deadlines" - **OPM**.

This statement suggests that managers accept 'delays' and schedule updates as reality and that there isn't so much they can do to eliminate the risk of time and cost overruns. They instead focus their energy on making sure that their plans are as realistic as possible and that contingency plans are devised to deal with unforeseen issues or incidents that could disrupt operations and undermine their firms' abilities to stay on schedule and on budget.

5.2.4 Theme D: Perception of Lean Construction

The participants were asked about what they knew about Lean management and whether they thought that Lean principles and practices were applicable to the Saudi construction industry. Generally, the participants seemed to have a positive attitude towards Lean and supported the idea of using Lean management practices to help project managers to reduce costs and improve quality. For example, one participant stated: "I think Lean is a concept that makes processes more valuable and accurate by applying specific rules to gain less defects and delay, also to reduce cost and improve the quality" - **PE**. The participants also seemed to associate Lean adoption with improvements in operational efficiency, management effectiveness and most crucially with cost savings. For instance, one participant explained that, to him, Lean construction was all about "applying modern techniques to achieve efficient and effective building and construction plans on time and minimal cost" - **CPM**. His statement didn't come as a surprise at all. It is understood that the adoption and operationalisation of Lean practices leads to notable improvements in a variety of areas, particularly in operations. Several empirical studies in the literature have reported that the adoption of 'Lean Construction' tools and techniques provides construction firms with numerous benefits. For example, Ahmed et al. (2020) found that the adoption of Lean principles helped Bangladeshi construction firms to make significant improvements, especially in "quality, safety, cost, productivity, and environmental level".

In an attempt to dig deeper into the participants' perceptions, the author asked a few follow up questions about the positive as well as the negative results of using Lean Construction tools. As part of their responses, the interviewees identified and discussed a variety of Lean tools and techniques. These included: root-cause analysis, visual management, integrated planning and procurement, process mapping, design management, off-site fabrication, and others. For example, one of the participants stated:

> "We work really hard to keep costs low and to improve our performance. We always try to identify the roots of problems and eliminate them and also develop plans and tactics to prevent them from happing again. We review our plans on a weekly basis and we work collaboratively with other teams and business partners to achieve our shared goals and objectives. We always seek new ways to reduce cost, reduce delays, boost productivity and maximise our profit margins" - **CPE-1**.

The participants' perception of Lean appears to be shaped by the positive outcomes associated with its adoption such as better communication, closer collaboration, fewer defects, improved quality, stronger stakeholder relationships, enhanced information flow, and most importantly greater bottom-line results. One participant claimed that their company had been able to make "savings of as much as $300,000 a year as a result of the adoption of Lean-friendly practices such as collaborative planning and more frequent on-time deliveries of supplies" - **PE**. Another interviewee stated that "as a result of the adoption of Leaner construction tools and practices, information is flowing much more smoothly between teams and across different hierarchical levels, which improved our awareness of what's going on at the operational level" - **PA-1**. Efficiency optimisation is also typically associated with Lean adoption. One participant explained:

> "As I understand it; being Lean means being more efficient. Our company has been obsessed with finding new ways of improving its operational efficiency, reduce costs and maximise financial gains. Lean fits perfectly well into our company's objectives. What I am trying to say is that even though we don't use the 'Lean Construction' banner, many of our operational practices are consistent with the principles of Lean" - **CPD-2**.

On the other hand, two out of the ten participants (20%) claimed that the adoption of Lean construction practices could lead to negative consequences such as cultures clash; operational disruption; lower than expected return-on-investment; higher overhead costs and organisational resistance. Lean is known to demand significant cultural shift towards continuous quality improvement mindsets and work practices. It isn't always easy for organisations to abandon their well-established routines and practices and replace them with Lean-friendly alternatives. Hence, not all firms reap the many benefits of Lean management. In fact, fewer firms succeed to operationalise the principles of Lean construction than fail to achieve the desired results. Most failures are attributed to cultural inconsistency and organisational resistance. One of the participants said:

> "I know that Lean is good for our company, but I am sure that there're workers who do not care about it and don't want to have anything to do with its implementation. This is maybe because being more efficient and Lean demands greater effort and hard work. As you know, not a lot of people like working harder, especially if they don't get extra cash for the additional work they have to do" - **OPM**.

5.2.5 Theme E: Drivers and Benefits of Lean Construction

The interviews also discussed the perceived benefits and drivers of Lean construction in the context of the Saudi construction industry as a whole and of the case-study firm in particular. The participants highlighted a variety of benefits which they believe encouraged their firm to embrace the principles of Lean construction. The identified benefits included: greater value for money; greater returns on investment; improved quality; improved operational efficiency; reduced cost; higher client satisfaction levels; improved public image; and most importantly reduced disruptions and unnecessary delays. A project manager stated:

> "When one understands the extent to which Lean can help companies to optimise their operational performance, he can't resist glorifying its many benefits. I personally think that Lean would help our company substantially, particularly in relation to efficiency, quality, safety, site conditions, personnel relations, and profitability, of course. What encourages the management most, frankly, is its cost reduction potential" - **CPD-1**.

This statement indicates that the firm's managers recognise the huge improvement potential of Lean construction, but they are far more interested in the practices which can help them to reduce cost of operations than in other practices. However, this attitude isn't shared by other workers. A construction engineer, for example, stated that their aim was to "deliver greater value to our clients. If Lean can help us to do that, we will welcome it with open arms. In my opinion, we should always keep our eyes on our clients' satisfaction. If they are satisfied, then it means we have done a great job and I don't care which system we use to achieve this goal as long as we achieve the goal at the end" - **CPE-1**. Unlike managers, engineers appear less concerned about cost than the accomplishment of their objectives. This could mean that it is possible for a company's different stakeholders to be driven and motivated by different benefits of Lean construction. Workers would probably be driven by practices that offer them a bigger voice and a say in decision-making processes, whereas managers would perhaps be more interested in initiatives which enable them to achieve their performance targets efficiently and timely.

The survey results also indicate that the adoption of pro-Lean practices, provides benefits to a wide range of stakeholders and in a variety of areas. Table 5:7; Table 5:8 and Table 5:9 show that Lean construction results in huge improvements in the areas of design, project management and organisational management. For example, in the area of design, 27 of the participants either agreed or strongly agreed that the adoption of Lean construction tools helps to 'solve potential constructability problems'. Also, 28 of the participants indicated that the adoption of Lean construction practices helps project managers to 'reduce lead-time, cost and throughput'. Similarly, 21 participants agreed and 5 participants strongly agreed that pro-Lean culture and tools 'motivates employees and shapes their behaviour'.

The interviews discussed several of Lean's tools and techniques that apply to the construction industry and tried to gauge the participants' opinions of, and attitudes toward, each one of them. For example, a construction manager was asked whether he thought "Heijunka" or

"Level Scheduling" would help him do a better job in terms of efficiency. He initially wasn't sure what the primary purpose of the tool was, but after the author clarified its applications and common uses, he said:

> "[...] as you probably know, not all of Lean's tools apply to our company or even to our industry. We have to be selective in terms of which tools are beneficial to our firm and which aren't. I don't think Heijunka would help me with my job. It sounds like it is more relevant to manufacturers than to us. Yes we want to reduce our lead time and complete projects on time, but Heijunka seems concerned with production lead-time [...]" - **CPM**.

Another Lean practice which the author discussed with the interviewees was "Kaizen". This is very popular and applies to almost all kinds of organisations and industries because it deals quality management and facilitates continuous improvement of products, services, processes, procedures, etc. A construction manager was very keen to express his interest in Lean tools the likes of Kaizen. He stated that his company was "very interested in Kaizen and other tools that can help us save costs, reduce time, boost efficiency and improve our quality. I personally like Kaizen. I like its ideas and I like what it's trying to do. We use it to some extent to find solutions to our problems and to prevent problems from happening again in the future" - **CPM**. His statement didn't come as a surprise at all. Kaizen isn't difficult to adopt and actualise. It only requires firms to put its most talented employees in cross-functional teams whose purposes are to work closely and collaboratively to investigate persistent quality problems and to put forth practical solutions to these problems. What is more interesting about Kaizen is that it encourages and facilitates the devolution of decision-making powers to the lower levels of the organisational hierarchy and to shopfloor quality-improvement teams in particular.

Interestingly, the survey results indicate that 'process mapping' is the most popular Lean management tool in the context of Saudi construction industry (*Refer* to Table 5:10). Other popular tools and practices included 'discrete event simulation' and 'daily huddle meetings', being the second and third most popular practices respectively. It seems that the popularity of Lean construction tools in the Saudi construction industry is influenced to a large extent by the simplicity and ease of the use of the tool(s) in question as the simpler tools appear to be more popular than the more complex, comprehensive practices.

5.2.6 Theme F: Enablers and Facilitators of Lean Construction

The interviews also studied the enablers and facilitators of Lean construction. Several factors were highlighted by the participants. These may be divided into four main groups; namely, motivational factors, project-related factors, firm-specific factors and technical factors. First, the interviewees think that the success of any Lean construction initiative depends heavily on senior management's commitment and motivation to allocate the needed resources and the right personnel to implementation projects. One participant argued that LC practices couldn't be successfully implemented without human resources and "effective means of communication and collaboration" - **PA-2**. He explained that having good systems of communication and knowledge sharing motivates workers participate in implementation efforts and to be more involved in their company's problem-solving and solution-finding efforts. Another participant also argued that "without resources, both managers and workers will be de-motivated to act. How do you expect us to implement and operate a certain system or practice if you don't provide us with the right resources which we need to make your wishes come true?" - **CPE-1**. The participants also identified several other important factors; namely, employees' morale, awareness, incentives and government pressure. Such factors are believed to influence workers' attitudes to Lean and affect their behavioural responses to managers' demands and expectations. An employee argued that their company "really needs to have a good reward system and rewards that are good enough to incentivise us and to encourage us to continue performing well. Most of us want to be rewarded one way or another for the hard work we put in for this company. I am sure that without very good incentive mechanisms, our managers will find it very difficult to boost participation and to convince workers to engage more with continuous improvement" - **CPE-2**.

Second, the interviews also highlighted a range of project-related enablers or facilitators such as training, morning huddles, project owners' satisfaction, and value-stream mapping. Most of the participants identified 'on-site training' on the use of Lean's tools and techniques as a very important facilitator for Lean construction practices' implementation. An employee stated:

> "As you of course know, training is essential for the success of new programmes. It helps workers to learn about the new system and how to operate it. It also encourages workers to engage with managers, especially at the operational level. Most people like to know where and why they are going, so training is important to answer most of their questions and to give them a sense of direction" - **CPD-1**.

This statement makes good sense in terms of how training is crucial for successful adoption and operationalisation of efficiency-improving systems of management. The importance of training can't be overemphasised, but what some fail to understand is that certain firms do not have the financial resources or the time to train all staff. This is particularly the case for many small construction firms in Saudi Arabia. Larger and more resourceful firms are in a far better position to fund and run extensive training workshops for their workers than smaller ones. So, Lean's training should be provided, initially, to people in leadership positions who will be directly involved in the implementation of its initiatives such as on-site supervisors and team leaders. At a later stage, training workshops should target all workers who will be directly affected by the new initiative(s). Doing so would help to reduce organisational resistance and workers' reluctance to participate in, and engage with, managers' implementation efforts.

Moreover, project owners' satisfaction with construction firms' Lean practices was identified as a very important driver for Lean's adoption. A participant claimed that their company was encouraged to adopt more Lean tools and techniques by clients' satisfaction. He explained that Lean's techniques such as value-stream mapping helped their company identify and eliminate non-value-adding activities and to improve its operational efficiency which in turn enabled it to meet clients' needs and expectations. He also argued that workers' "involvement in briefings and morning huddles give us a chance to discuss plans, highlight issues and put forth ideas on how we can best achieve our team's goals safely and efficiently" - **CPE-2**. He argued that early-morning meetings were as important as training workshops as they provide workers with important information and improve their awareness of what's happening on the site.

Thirdly, the participants also discussed a range of firm-specific factors that had an impact on the implementation of pro-Lean initiatives. These included: management commitment; good leadership; awareness level; and pro-Lean investment. Five out of the ten participants (50%) highlighted 'management commitment' as a critical enabler of Lean construction. This didn't come as a surprise at all since management commitment plays a significantly important role in shaping workers' attitudes and behaviours as well as in the allocation of much-needed resources. In fact, there is strong evidence in the literature which suggests that without the commitment of senior managers, change initiatives will be destined to fail. Besides, a participant argued:

> "There are many factors which affect the implementation of Lean construction and whether it turns out to be a success or a failure. For example, all managers, small and big, have to show a strong desire to implement Lean successfully no matter what. This desire will send a clear message to all workers that they are expected to engage fully with the implementation efforts and that reluctance to participate will be penalised" - **APM**.

This statement does not only emphasise the importance of managers' expression of commitment, but it also indicates that it is common for Saudi firms to use different forms of punishment to force staff to think or behave in a certain way. For example, employees who might refuse to participate in Lean construction's implementation could be deprived of bonuses, pay raises and even job promotions as a punishment. Some firms go as far as cutting down pay rates and making deductions from wages as a penalty for their uncooperative behaviours.

Moreover, having a strong leadership that's willing to do whatever necessary to implement Lean tools and techniques is also very important because followers [workers] need leaders who lead by example. So if the leaders have pro-Lean attitudes, their followers are likely to have consistent attitudes which are essential for successful operationalisation of Lean initiatives. Workers' awareness of Lean's drivers, applications, benefits and implications is as important as leaders' commitment. A construction engineer argued that "training is critically important for the adoption and use of any new system. Training improves awareness and greater awareness helps to create favourable opinions about the tools or systems that the company is trying to adopt and favourable opinions are essential for workers to be internally-motivated to participate and support their managers' struggle to implement the new systems and to improve performance" - **CPE-1**.

Another issue that had been highlighted by the participants was leaders' 'willingness to invest' in Lean construction initiatives. Three out of the ten participants (30%) said that Lean tools and techniques aren't always easy to implement or operate. Their implementation requires so many financial and human resources. Thus, a company's leaders must be willing to make long-term investments in initiatives whose benefits might take months if not years to materials. For some company leaders, this kind of risk is a too big ask. For example, one of the participants indicated that the case-study firm had been reluctant to invest in efficiency improvement initiatives:

> "As you know, we work in a rapidly growing industry. Things happen really fast here. We rarely have time to sit down and think about what we need to do in order to boost our productivity or to enhance our efficiency. My superiors are even busier than me, so we like to focus on the things which make us money here and now. The idea of making our construction operations, Lean and more efficient is great, but as I said we are too busy most of the time. But don't understand me wrong, we do implement some changes here and there all the time to ensure that our work is done efficiently and with the best quality and as per our clients' requirements" - **OPM**.

This statement suggests that the case-study firm's leadership isn't against the idea of Lean construction, but the firm's operational circumstances and the competitive nature of industry restrict its ability to adopt all of Lean's tools and techniques. It appears that the firm's leaders have favourable attitudes toward Lean, but are reluctant to invest their time and cash in ideas that wouldn't provide them with immediate returns on their investments.

Fourth, the interviews revealed several technical factors which were said to be important for successful implementation of pro-Lean initiatives in the Saudi construction industry. These factors included: understanding of Lean's technicalities; use of Lean consultants; technical skills and competencies; and availability of pro-Lean resources. The interviewees indicated that having a good understanding of the technical needs and requirements of Lean construction is critically important for its successful implementation. In fact, lack of understanding and unfamiliarity with Lean's technicalities doesn't only hinder its adoption, but also destines its implementation efforts to failure. An engineer explained that "we still don't have sufficient knowledge of many of Lean's tools and techniques, so how do you expect us to successfully adopt and operate a system that we don't fully understand? We need training and we need more information about Lean's requirements so that we know what we need to do in order to implement its tools well and reap its benefits" - **CPE-1**.

Four out of the ten participants (40%) also highlighted the importance of using consultants and consultancy firms. They claimed that using experienced consultants was essential not only to provide managers with useful insights into the technical side of Lean's tools and techniques, but also to devise appropriate implementation strategies and plans that account for all, or at least most, of the barriers or obstacles that construction firms face when trying to go Lean. A participant stated:

> "I agree with you. Consultants are important. Lean isn't something that we developed internally so we don't know everything about it. We need help from external experts and consultants in dealing with the complexities of implementation. In my opinion, we should rely on our internal people as much as possible, but for more complicated issues we would really need the assistance of consultants. They will surely change us too much for their services, but that's still better than having a failed system" - **CPD-1**.

Moreover, six out of the ten participants (60%) discussed the need for the right skills and competencies for workers to embrace Lean's principles and effectively operate its tools and techniques. It is almost impossible for firms to successfully transition towards Lean construction without their staff having the skills and competencies needed to actualise Lean's principles. Workers should not be expected to effectively operate or use a tool or technique that they haven't been adequately trained on. The case-study firm appears to have done just enough to ensure that its workers have the skills needed to achieve optimal operational performance. A participant claimed:

> "Our company provides us with frequent training to update or upgrade our skills and make sure that we can do our jobs properly. Some workshops are more frequent than others. Safety workshops are regular. Other training workshops are less frequent and depend on our needs. For example, when the new system or procedure is implemented, we get invited to training sessions which often involve presentations and simulation games and other interactive activities" - **CPE-2**.

Two out of the ten participants (20%) also discussed the availability of pro-Lean resources. They argued that the availability of systems, practices and routines that were consistent with Lean's requirements and needs, facilitates the adoption of pro-Lean practices. Their arguments were based on the assumption that the existence of compatible systems and cultures would make managers' jobs far easier as less changes would have to be made to day-to-day activities which in turn reduces the risk of behavioural implications such as 'organisational resistance'. One project manager said: "many of the things we have here already complied with the requirements of Lean, so I do not usually have to make dramatic changes when new policies or procedures are introduced. For example, we appreciate the benefits of standardisation and most of our processes and procedures have been standardised and staff have to comply strictly with the standards. We don't take violations of standards lightly. Negative acts are penalised harshly" - **APM**.

The survey results also indicate that 'regular training of workforce' is perceived as the most important enabler of Lean construction (*Refer* to Table 5:13). 25 participants either agreed or strongly agreed that training was significantly important to Lean construction's success. This was followed by the 'integration of teams' and 'acceptance of Lean principles'.

5.2.7 Theme G: Barriers and Challenges of Lean Construction

The participants were asked questions about the challenges and barriers that their company had faced during the implementation and operationalisation of Lean-friendly practices. Their responses highlighted several common barriers and challenges. They included: organisational / cultural resistance, short-sighted investment strategies / policies, lengthy implementation timeline, costly implementation processes, misunderstanding of principles, top managements' impatience, lack of relevant knowledge and skills, complexity, lack of workers' buy-in, and lack of both intrinsic and extrinsic rewards / incentives. First, two of the ten participants (20%) claimed that not all of the workers were interested in the adoption of efficiency-improving practices. In fact, there were people who opposed the idea of standardisation which necessitates that every activity a worker does have to follow a set of pre-defined procedures. Standardisation of work activities provides consistency, but it could also make organisational processes rigid. For example, one participant argued:

> "I don't understand - why do we have to change the way we do things? Why must we make things more complicated? I believe that something shouldn't be fixed until it is broken. I don't think Lean is bad, but I do believe that we do things efficiently enough and we don't need foreign practices which make our jobs harder" - **PA-1**.

Second, senior managers' short-sighted investment policy has also been identified as a major barrier to Lean construction practices. Four out of the ten participants (40%) claimed that managers' failure to appreciate the long-term benefits of Lean construction was what obstructed the adoption of efficiency-improving practices. One interviewee said: "our bosses look beneath their feet and don't have a clear vision of what investments they should make in order to sustain our firm's growth and profitability. If they were visionaries, they would have appreciated the substantial potential of Lean construction tactics and practices" - **CPE-1**. It was argued that lack of a long-term investment strategy undermined senior managers' support and commitment to Lean. This isn't surprising at all because managers typically don't commit to anything which does not provide good returns on investment.

Third, the participants also identified 'lengthy implementation timeline' as a major barrier to the adoption and implementation of Lean construction practices. This is a common problem in almost all companies because the implementation of Lean doesn't happen overnight. It takes a long time to institutionalise Lean's principles and to put its practices into action. Also, getting employees to modify or change their attitudes and behaviours in line with Lean's requirements is neither easy nor straightforward. One manager explained:

> "Achieving optimal operational performance through Lean or through other means of efficiency improvement is an endless journey full of ups and downs. It is a very long process. Don't think that optimal performance is easily achieved or can be achieved in a short time. It takes time to train staff, develop structures and systems, implement the processes and procedures and get the changes adopted" - **OPM**.

Fourth, Lean construction involves 'costly implementation processes', so not all organisations can afford to adopt all of Lean's tools and techniques. The participants discussed the fact that the cost of implementing Lean's practices was sometimes too high to induce the right level of commitment from senior managers. Managers' recognise the potential, long-term benefits of Lean, but sometimes hesitate to commit the required financial, human and physical resources needed to successfully adopt and operationalise Lean's tools and techniques. One participant argued that "Lean's implementation involves many processes and each process is more costly than the next one. Companies have to first understand the principles and the systems they are trying to implement. This takes time and effort. Then, they have to invest a lot of money on staff's training and a lot of time trying to convince workers of the need for, and urgency of the new systems. The implementation process itself would take a long time and so much money would need to be spent on consultants. Consultants, of course, charge too much" - **PA-1**.

Lean's implementation processes could also lead to firms' incurring additional, indirect costs, especially if their critical day-to-day business activities were disrupted. Usually consultants try to ensure that Lean's implementation does not disrupt business operations, but this is not always possible, particularly when the process involves the implementation of major systems (e.g. Just-In-Time or JIT). Lengthy disruptions can be very costly.

Fifth, the interviewees also identified 'misunderstanding of Lean's principles' as a barrier to its adoption and implementation. It's not uncommon for practitioners as well as academics to misunderstand the underlying principles of Lean management. Some people perceive Lean as a cost-cutting philosophy that focuses on reducing staff numbers, reducing the time workers take to complete tasks and excessive standardisation of shop floor activities. Others perceive Lean as another quality management philosophy whose primary purpose is to achieve optimal product quality. In reality, Lean's purpose, principles and impact are much broader than that. It helps organisations to optimise their performance in almost all areas, but its impact is usually more significant and obvious in operational areas. One of the participants stated:

> "You shouldn't blame people for not supporting the idea of having Leaner operations. Some people here see Lean as nothing more than cut-cut-cut. Management uses it to cut staff numbers, to cut wages and to cut how long we take to complete a job. It can get really tiring and frustrating having to work harder and faster all the time trying to keep up with tight and unrealistic deadlines" - **PA-1**.

Sixth, 'top managements' impatience' was also reported as a major barrier to Lean. It is apparently typical for senior managers to have too high and too impatient expectations of Lean's tools, techniques and systems. Some managers think that their firms will begin to reap the benefits of Lean Construction as soon as its practices are adopted and operationalised. It's this kind of patience which undermines top management's long-term commitment to Lean and puts excessive pressure on workers to meet unrealistic deadlines and performance targets. An interviewee discussed managers' impatience and claimed that:

> "[...] managers rush us through the implementation processes of efficiency initiatives thinking that as soon as the new systems and procedures are implemented, the benefits and gains will start raining from the sky. Their attitude and understanding is so out of touch with the operational reality. It takes time for people to get used to new systems and it takes time for the systems to work optimally. We shouldn't be rushed because if you rush us, we won't work wholeheartedly and that will surely have a negative effect on time, cost and productivity performance" - **CPE-2**.

Seventh, the participants also discussed how 'lack of relevant knowledge and skills' could hinder their company's effort to actualise the principles of Lean Construction. Two of the ten participants (20%) claimed that many workers and managers don't have the knowledge or the right set of skills which are needed to put Lean principles into action. This claim has been found to be true. When asked to define what 'Lean' meant, one participant said:

> "It depends from sector to another. But, I think Lean is a concept that makes processes more valuable and accurate by applying specific rules to gain less defects and delay, also to reduce cost and improve the quality" - **CPD-1**.

It is hard to see how Lean construction's tools and techniques could be adopted successfully and operated effectively without the right level of awareness and set of skills. It is important that managers recognise and appreciate the need for extensive training workshops to improve staff's knowledge of Lean's principles and provide them with the skills and competencies they need to operate and maintain Lean's tools and techniques.

Eighth, four of the ten participants (40%) considered some of Lean's practices to be far too "complex" to work for a construction firm. It isn't uncommon for workers to complain about the 'complexity' of Lean management. As previously highlighted, Lean's impact goes further and deeper than the operational side of firms' business activities to include all activities whose efficiency and quality may be optimised using one or more of its tools or techniques. One participant said:

> "You might think that Lean makes our jobs better, but to be honest, it makes them so much harder. It is complex. It demands time and energy. I believe if the conventional system and procedures work, why change them. We need to make things simpler" - **PA-1**.

Ninth, two of the ten participants (20%) also indicated that 'lack of workers' buy-in' had hindered the adoption of efficiency improvement initiatives. There were claims that workers didn't care much about the company's efforts to optimise its operational efficiency and rarely engaged or participated in the implementation processes. One participant stated:

> "As you know, the implementation of any new system requires workers and teams to work collaboratively and harmoniously together to achieve collective goals. This isn't the case with this company. If you worked here, you would see for yourself how poorly workers communicate with each other and how cooperation and teamwork is lacking" - **APM**.

Lastly, the interviewees highlighted 'lack of incentives' as a problem that's standing in the way of employees' buy-in. Generally, people need some form of incentive to be motivated or to display a willingness to engage with any change initiative. Certain people are motivated by intrinsic rewards, while others need tangible, extrinsic rewards. This, of course, applies to the employees of the BBC. A participant argued: "workers need to be appreciated for the hard work they do for our company. They should be given extra pay or bonuses for their performance. Without this, managers shouldn't expect workers to commit to their improvement efforts. I myself feel unappreciated. I don't mean I should receive extra cash, but we [workers] should at least be recognised for our best performance" - **PA-1**. This argument highlights the need for a 'reward management system' which will ensure that workers who are involved in, and display greater commitment to, Lean management are adequately incentivised and reward for their contributions to the implementation and operationalisation of pro-Lean initiatives.

The survey results also indicate that 'bureaucracy and instability' are a significant barrier to the diffusion and adoption of Lean construction practices in the Saudi construction sector (*Refer* to Table 5:12). Also, 20 participants either agreed or strongly agreed that 'resistance to change' was a significant barrier to Lean construction's success. This was followed by 'lack of proper training' and 'lack of application of fundamental techniques' in the third and fourth places respectively.

5.3 Findings from Questionnaire

The author administered questionnaires to the project participants on the site. The questionnaire was designed to investigate the factors that contribute to project delay in construction projects in Saudi Arabia. The questionnaire was designed to get the most out of the responses. The first section of the questionnaire focused on requesting personal information of the respondents; The second and third sections focused on finding out the participants' level of involvement with Lean project management in construction and identifying the different construction project techniques, including the main causes of delay experienced in construction projects. Only the second and third parts of the questionnaire targeted the respondents' perceptions of the causes of delay on construction projects. The questionnaire was formatted using a 4-point Likert scale, data samples were analysed adopting severity index, ranking and simple percentages. The questionnaire section focused on obtaining general information administered to 49 respondents. The collected data was analysed using percentage, mean item score ranking, and the use of descriptive statistics. Factors that have the likelihood of causing delay in construction were ranked using severity index. The four-scale in the questionnaire forms the response variables which are mapped with the factors used to obtain the severity index.

In carrying out this research, the Ranking Indices of Importance (RII) statistical representation were used for measuring the extent to which the occurrence of an outcome exists. RII is commonly used to measure the extent to which the occurrence of an outcome exists (Sergent and Firth, 2006). The following formula was used to calculate RII.

$$RII = \frac{\check{x}}{k}$$

where $\check{x}$ = mean = $\frac{\sum fx}{\sum f}$

k = the maximum point on Likert scale

x = points on the Likert scale (1, 2, 3, 4, …)

ranking weight: *strongly agreed = 4, agree = 3, disagree = 2 and strongly disagree = 1* also, *very important = 4, important = 3, slightly important = 2 and not important = 1.*

f = frequency of respondents choice

Furthermore, for interpretation requirement for *RII* values:

RII is ranked from the highest to the lowest.

That is, if $RII < 0.60$, the items is considered to have low rating

$0.60 < RII < 0.8$, the item is considered to have high rating

$RII \geq 0.8$, the item is considered to have very high rating.

5.3.1 Part 1: Descriptive Statistics

The respondents for the questionnaire administration comprised of the construction workers and project manager. A percentage breakdown of the respondents' participation is presented in Table 5:1 and the details of the questionnaire including their corresponding responses are discussed below. All of the respondents 49 (100%) provided responses as shown in Table 5:1. In terms of position, at least 6 participants identified themselves as team supervisors, senior engineers, project engineers, project managers, and engineers.

Table 5: 1 - Position of the Respondents

Participants	Respondents	Percentage
Executive director	3	6.1
Team supervisor	6	12.2
Senior engineer	6	12.2
Project engineer	6	12.2
Construction engineer	5	10.2
Project manager	6	12.2
CEO	2	4.2
Civil engineer	7	14.3
Senior Manager	4	8.2
Consultant	4	8.2
TOTAL	**49**	**100%**

In terms of profession, most of the participants belonged to engineering and architecture as shown in Table 5:2. This is presented using percentage scores - Civil Engineer 15 (30.6%), Architect 11 (22.4), Quantity surveyor 8 (16.4%) and Others 15 (30.6%).

Table 5: 2 - What is your profession?

Participants	Respondents	Percentage
Civil Engineer	15	30.6
Architect	11	22.4
Quantity surveyor	8	16.4
Others	15	30.6
TOTAL	**49**	**100**

The follow up question to Table 5:2 asked the participants about how long they had been working in the Saudi construction industry. Their responses are presented in Table 5:3 below. Those who have been working between 16-20 years emerged as 12 (24.49%); this is followed by 6-10 years, 10 (20.41); between 11-15 years, 9 (18.37).

Table 5: 3 - How long have you worked in the construction industry?

Total respondents	Frequency	Percentage
1 – 5 years	4	8.16
6 – 10 years	10	20.41
11 – 15 years	9	18.37
16 – 20 years	12	24.49
21 – 25 years	7	14.29
Over 25 years	2	4.08
No response	5	10.20
TOTAL	**49**	**100**

The next question asked the participants about the main activities of their departments. The participants' responses are presented in Table 5:4. Most of the participants indicated that their department was responsible for construction - 20 (40.82%), 14 (28.5%) respondents indicated that they were responsible for design and 13 (26.53%) participants indicated that they were responsible for both design and construction

Table 5: 4 - What is the main activity of your department?

Total respondents	Frequency	Percentage
Design	14	28.57
Construction	20	40.82
Both design and construction	13	26.53
No response	2	4.08
TOTAL	**49**	**100**

5.3.2 Part 2: Awareness and Knowledge of Management Practices

The second part of the questionnaire focused on participants' levels of awareness. They were firstly asked about whether they had attended any project management courses recently. Most of the respondents (66.6%) indicated YES and only 34.4% of them indicated NO as shown in Table 5:5 below.

Table 5: 5 - Did you study any project management course?

Total respondents	Frequency	Percentage
Yes	29	59.2
No	11	22.4
Not Applicable	9	8.4
TOTAL	**49**	**100**

Secondly, the participants were asked to assess their knowledge of Lean project management. Their responses indicate that most of them (56.1%) had "average" knowledge of Lean project management and at least 20% of them had "low" awareness of the matter as shown in Table 5:6 below. Lack of knowledge, of course, undermines managers' efforts to implement Lean Construction's tools and techniques successfully.

Table 5: 6 - Evaluate your knowledge of Lean Project Management

Total respondents	Frequency	Percentage
Low	10	20.40
Average	27	56.10
Advance	5	10.20
No Response	8	16.32
TOTAL	**32**	**100**

5.3.3 Part 3: Perceived Benefits of Lean Construction

The third part of the questionnaire examined the participants' perception of how Lean construction could help their company to improve its performance in three areas; namely, design, project management, and organisational management. The participants were asked to indicate their levels of agreement with corresponding statements on 4-point Likert scales as shown in Table 5:7, Table 5:8 and Table 5:9. Firstly, most of the participants strongly agreed that Lean would help construction firms to: eliminate waste and non-value adding activities; solve potential constructability problems; and aid effective communication among teams. Table 5:7 shows that 12 participants agreed and another 16 participants strongly agreed that Lean construction 'eliminates waste and non-value adding activities'. This particular benefit was ranked first. 27 of the participants also either agreed or strongly agreed that Lean construction 'solves potential constructability problems'. This was followed by the statement suggesting that Lean construction 'aids effective communication among teams' in the third place.

These findings are consistent with the findings of Ogunbiyi et al. (2014) whose research examined the impact of Lean's techniques on the sustainability of British construction firms. Their analyses revealed that the adoption of Lean practices often helped construction firms to improve their corporate image, competitiveness, productivity, quality, compliance, customers' satisfaction, business sustainability, environmental performance and process flow. They also found that the use of Lean tools like JIT, Kanban, and value stream mapping enabled construction firms to reduce waste, maximise value and improve their safety performance.

A more recent study by Ahmed et al. (2020) investigated the benefits and challenges of Lean implementation in the Bangladeshi construction industry. Their investigation concluded that despite the difficulties of Lean construction's practices' implementation, they provide many important benefits such as: reduced costs, improved productivity, enhanced safety, optimised efficiency, improved quality and better environmental management. They also found that the adoption of Lean facilitates the deployment of state-of-the-art technologies and systems.

Table 5: 7 - Benefits of Lean in Design

	Weighted frequency							
Advantages	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	$\sum f$	$\bar{x}$	**RII**	**Rank**
Leads to better technological efficiency	6	18	4	0	28	3.07	0.77	5th
Solves potential constructability problems	12	15	1	0	28	3.39	0.85	2nd
Reduces project development time and cost	10	13	5	0	28	3.18	0.80	4th
Assures supervised quality control procedures	7	16	5	0	28	3.07	0.77	6th
Aids effective communication among teams	9	18	1	0	28	3.32	0.83	3rd
Eliminates waste and non-value adding activities	16	12	0	0	28	3.57	0.89	1st

Secondly, the respondents were asked to indicate their perceptions of how Lean could help construction firms to improve their project management performance using a 4-point Likert scale. Most of the participants strongly agreed that Lean would help their firms to: reduce lead-time, cost and throughput; help in standardisation of work practices; and improve safety and environmental issues as shown in Table 5:8. 16 participants agreed and another 12 participants strongly agreed that Lean construction 'reduces lead-time, cost and throughput'. The participants also indicated that Lean construction facilitates a systematic 'standardisation of work practices', but 6 participants strongly agreed with this statement. Moreover, 18 participants agreed and 5 participants strongly agreed that Lean construction 'improves safety and environmental issues'. Very few participants disagreed with it.

This research's findings are similar to the findings of Al-Aomar (2012) and Ma et al. (2018). Al-Aomar (2012) examined the impact of Lean project management on construction firms' performance. He found that Lean could help construction firms to deal with 27 types of waste such as defects, delays and overprocessing. Ma et al. (2018) also studied the impact of Lean on the project's performance in the context of built-environment projects. They found that the adoption of Lean's tools and techniques could help construction firms to significantly improve the efficiency of their operations, optimise productivity, reduce costs and mitigate the risk of delays.

Table 5: 8 - Benefits of Lean in Project Management

	Weighted frequency (f)							
Advantages	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	$\sum f$	$\bar{x}$	**RII**	**Rank**
Improves safety and environmental issues	5	18	5	0	28	3.00	0.75	3rd
Reduces lead-time, cost and throughput	12	16	0	0	28	3.43	0.86	1st
Helps to identify constraint within construction	5	17	6	0	28	2.96	0.50	7th
Focuses on value than cost	5	11	7	0	27	2.39	0.60	6th
Optimizes resource delivery schedule	6	11	10	0	27	2.75	0.69	5th
Aids reduction in on-site transportation	8	10	9	0	27	2.86	0.72	4th
Results in standardisation of work practices	6	17	5	0	28	3.04	0.76	2nd

Thirdly, the participants were asked to indicate their perceptions of Lean construction's impact on organisational management using a 4-point Likert scale as shown in Table 5:9. It was found that most of the respondents believed that Lean initiatives would enable their firms to: motivate employees and shape their behaviours; integrate supply chain; and increase staff awareness of organisational problems. Table 5:9 shows that 21 participants agreed and another 5 participants strongly agreed that Lean 'motivates employees and shapes their behaviour'. This particular statement was ranked top. It was followed by the statement indicating that Lean construction 'facilitates integration of supply chain'. This statement was supported by 19 participants who either agreed or strongly agreed with it.

There are numerous studies in the academic literature whose findings are consistent with the findings of this research. For example, Jørgensen and Emmitt (2009) investigated the impact of Lean on organisational integration and found that Lean construction practices enable firms to identify value, improve project delivery, improve structure of delivery processes, optimise planning and scheduling operations, boost processes' transparency and provide more effective management and leadership. Another relevant study by Eriksson (2010) examined the impact of Lean's practices on supply chain's collaboration and performance. They found that the adoption of Lean helped construction firms to improve supply chain cooperation, team collaboration, workers' performance, short-term business objectives and long-term competitiveness. They concluded that Lean thinking has a positive, direct impact on construction firms' supply chains' performance.

A more recent study by Avelar et al. (2019) examined the impact of Lean's adoption on the performance of construction SMEs. They found that Lean construction practices didn't only help firms to boost the value of their products/services and eliminate waste or non-value-adding activities, but also to improve their approach to organisational management such as the way workers are recruited, trained and developed. They argued that the adoption of Lean construction would help firms to "achieve better management decisions" especially in relation to the issue of "overcoming the limited resources" (p. 362).

Table 5: 9 - Benefits of Lean in Organisational Management

	Weighted frequency (f)							
Advantages	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	$\sum f$	$\bar{x}$	**RII**	**Rank**
Increased awareness	7	12	9	0	28	2.93	0.73	3rd
Is similar to the traditional practices	1	10	17	0	28	2.43	0.61	8th
Has improved competitiveness and market share	5	15	7	0	27	2.93	0.73	4th
Motivates employees and shapes their behaviour	5	21	1	0	27	3.19	0.80	1st
Has complemented marketing effort	2	17	8	0	27	2.78	0.70	6th
Innovative sustainable competitive advantage	4	13	10	0	27	2.78	0.70	7th
Facilitates integration of supply chain	7	12	8	0	27	2.96	0.74	2nd
Enables construction performance improvement initiatives	7	10	10	0	27	2.89	0.72	5th

The survey outcomes shown in Table 5:7; Table 5:8 and Table 5:9 are, to a large extent, consistent with the statements made by the semi-structured interviews' participants. For example, several participants indicated that the adoption of pro-Lean practices helped the case-study organisation to improve quality, boost operational efficiency, reduce costs and most importantly reduce disruptions and unnecessary delays (*Refer* to Section 5.2.5).

5.3.4 Part 4: Experienced Impact of Lean Construction

The fourth part of the questionnaire asked the participants about which Lean construction's tools and techniques were commonly used by their organisation and their impact on performance (*See* Table 5:10 and Table 5:11). Firstly, the participants were asked to rate their perceptions of how important each tool/technique was for their organisation on a 4-point Likert scale. It has been found that most of the participants think that "process mapping" is very important for their organisation's performance. 13 participants thought that this factor was important, while 11 respondents indicated that it was very important for their organisation's performance. This was followed by "discrete event simulation" and "daily huddle meeting". These three tools/techniques aren't only been frequently used by the organisation but are also perceived to have the greatest impact on its performance. This finding is similar to the findings of Shurrab and Hussain (2018) who investigated the impact of Lean's tools and techniques on the performance of construction firms. Their study identified 21 techniques that were compatible with the needs and nature of the construction industry. These techniques were divided into six categories based on their area of impact. The study concluded that all of the 21 techniques had a positive impact on construction firms' economic performance. Also, Ogunbiyi et al. (2014) investigated the impact of Lean construction's tools and techniques on the performance of UK construction firms. They found that the use of 'daily huddle meetings', 'value analysis' and 'value stream mapping' helped British construction firms to improve their operational efficiency and their economic sustainability. They also found that the adoption of Lean construction's principles helps firms to improve their brand image, reduce waste, boost productivity, reduce costs, improve quality, maximise value and strengthen competitiveness.

This research's semi-structured interviews also indicated that training, morning huddles, and value-stream mapping were significantly important as enablers of Lean construction. In fact, most of the interviewees identified 'on-site training' on the use of Lean's tools and techniques such as 'daily huddle meetings' was very important for the success of Lean construction practices' implementation (*Refer* to Section 5.2.6).

Table 5: 10 - Lean's Tools & Techniques

Lean's Tools and Techniques	Very Important	Important	Slightly Important	Not Important	$\sum f$	$\bar{x}$	RII	Rank
Value Stream Mapping	12	11	3	0	26	3.35	0.84	7th
Kaizen	10	12	2	1	25	3.24	0.81	12th
A3 Thinking	12	8	6	0	26	3.23	0.81	13th
Work standardisation	12	8	5	1	26	3.19	0.80	16th
Six Sigma	12	10	4	0	26	3.31	0.83	9th
Error Proofing	12	10	3	1	26	3.23	0.81	14th
Workplace Organisation (5S)	11	12	4	0	27	3.26	0.82	10th
Visual Management	11	13	2	0	26	3.35	0.84	8th
Last Planner System	11	10	4	0	25	3.28	0.82	10th
Concurrent Engineering	11	14	1	0	26	3.39	0.85	4th
Daily huddle meeting	11	15	0	0	26	3.42	0.86	3rd
Value Analysis	12	10	3	1	26	3.27	0.82	11th
Total Quality Management	12	12	2	0	26	3.38	0.85	5th
Just-In-Time	11	14	1	0	26	3.38	0.85	6th
Process Mapping	11	13	1	1	26	3.42	0.86	1st
Discrete Event Simulation	11	10	1	0	22	3.45	0.86	2nd
Other	10	10	5	0	25	3.2	0.80	17th

Secondly, the participants were asked to indicate the impact of Lean construction's tools and techniques on different performance indicators and to highlight their importance as shown in Table 5:11. Most of the participants indicated that Lean's practices had helped their company to reduce "energy consumption", reduce "waste" and improve staff's participation in decision-making processes. These areas of improvement are perceived as more important than other areas of improvement such as workforce reduction and corporate image. In fact, 13 participants indicated that Lean construction's ability to offer significant "reduction in energy consumption" was very important. Similarly, 12 responses indicate that the participants perceived "reduction in waste" as very important.

The above findings are, again, consistent with the findings of numerous other empirical investigations. For example, Grenzfurtner and Gronalt (2020) investigated the impact of Lean's Kaizen and continuous improvement practices on the performance of construction firms. They found that the use of Kaizen had helped house-building firms to improve employees' involvement in improvement initiatives, to closely integrate and coordinate order fulfilment operations, and to prevent on-site failures. Another study by Bajjou and Chafi (2018) also investigated the impact of Lean's tools and techniques on the performance of Moroccan construction firms. They found that the adoption of Lean construction's practices had had a "positive impact, specifically on quality, safety and environmental level". Their conclusions indicate that Lean doesn't only help firms to reduce waste and improve operational efficiency, but also to improve the effectiveness by which the human and financial resources are managed. Similarly, Pandithawatta et al. (2019) examined the viability of employing Lean's techniques in conjunction with Green principles to improve construction firms' business and environmental performances. They concluded that the adoption of Lean's tools would almost always help firms to eliminate "waste while enhancing the construction process" which in turn reduces their environmental footprint.

Table 5: 11 - Impact of Lean Constforction's Tools/Techniques on Performance

Total respondents	Very Important	Important	Slightly Important	Not Important	∑f	$\bar{x}$	RII	Rank
Improved corporate image	10	9	5	2	26	3.04	0.76	15th
Improvement in innovation	11	10	4	1	26	3.19	0.80	11th
Increased competitive advantage	11	11	4	0	26	3.27	0.82	6th
Reduced cost, lead-time and throughput	11	12	3	0	26	3.31	0.83	5th
Improved process flow	11	10	4	1	26	3.19	0.80	10th
Increased compliance with customers expectations	11	10	3	2	26	3.15	0.79	14th
Improvement of environmental quality	11	10	4	1	26	3.19	0.80	9th
Increased employee morale, and commitment	11	10	5	0	26	3.23	0.81	7th
Reduction in material usage	11	10	5	2	26	3.31	0.83	4th
Reduction in energy consumption	13	9	4	0	26	3.69	0.92	1st
Reduction in waste	12	7	5	1	26	3.35	0.84	2nd
Reduction in water usage	9	11	6	0	26	3.12	0.78	
Increased productivity	10	11	5	0	26	3.19	0.80	8th
Improved Health and Safety	13	8	4	1	26	3.27	0.82	6th
Reduction in workforce	11	9	5	1	26	3.15	0.79	13th
Increased staff participation in decision making	11	8	3	4	26	3.31	0.83	3rd

5.3.5 Part 5: Barriers and Enablers of Lean Construction

The fifth part of the questionnaire explored the barriers and enablers of Lean construction. A 4-point Likert scale was used to gauge the participants' opinions and perceptions as shown in Table 5:12 and Table 5:13. Most of the participants indicated that (1) government bureaucracy and instability; (2) resistance to change; (3) lack of proper training and (4) lack of application of fundamental techniques were the main barriers to successful adoption and implementation of Lean construction's tools and techniques. 13 participants strongly agreed and another 12 participants agreed that "government bureaucracy and instability" undermine the diffusion and widespread adoption of Lean construction's tools and techniques in the Saudi construction industry. This barrier was ranked top by the participants. It was followed by "resistance to change" and "lack of proper training" in the second and third place respectively.

On the other hand, the participants indicated that (1) regular training of the workforce; (2) integration of teams and end-to-end supply chains; (3) wide acceptance of Lean's principles and (4) effective change management processes were critical for successful implementation of Lean's principles. Table 5:13 shows that 12 participants strongly agree and another 13 participants agree that "regular training of workforce" is very important for successful implementation of pro-Lean practices. This particular enabler was ranked top. It was followed by "integration of teams" and "acceptance of Lean principles" in the second and third place respectively with the support of at least 25 respondents.

The survey results are, somewhat, consistent with the interviews' results. For example, the interviewees indicated that management commitment; good leadership; awareness level; and pro-Lean investment were critical for the success of Lean construction in the context of Saudi construction firms (*Refer* to Section 5.2.6). The interviewees also indicated that organisational resistance, costly implementation processes, misunderstanding of principles, top managements' impatience, lack of workers' buy-in, and inadequate training were major barriers to the adoption and utilisation of pro-Lean practices (*Refer* to Section 5.3.7).

This research's findings didn't come as a surprise at all. There are numerous other empirical studies that have identified similar barriers and enablers. For instance, Ahmed and Sobuz, (2019) investigated the most common challenges Bangladeshi construction firms face when trying to implement and actualise Lean construction. Their investigation identified 41 barriers which were found to hinder the firms' efforts to transition toward Lean. They included "lack of awareness about Lean construction, lack of skills, training and Lean techniques, unwillingness to change the existing culture, lack of management commitment, fragmented and cyclic nature of the construction project and unavailing communication between all project participants". Another study by Sarhan et al. (2018) investigated Lean construction's barriers in the context of the Saudi construction industry. Their investigation identified 22 influential barriers that had, for many years, undermined the industry's efforts to achieve widespread adoption of Lean's tools and techniques. Their list of barriers included: lack of management commitment, workers' resistance, lack of cultural consistency and poor training. The issues of cultural resistance and lack of training have also been identified by Shang and Pheng (2014) as significant barriers to Lean construction. In their study of Lean construction, implementation in the Chinese construction industry, they found that firms' efforts to embrace Lean's principles and practices were hindered primarily by: The absence of pro-Lean culture, the "use of multi-layer subcontracting", short-termism, lack of support, and staff's reluctance to change their attitudes and work routines.

In terms of enablers, Sharma et al. (2016) investigated the most common enablers of Lean and found that "training" was the single most important enabler. They concluded that training had the "maximum driving power and the least dependence and hence has strong managerial significance". They identified several other enablers, but according to their simulation model, training was far more influential than all other enablers including management commitment. AlSehaimi et al. (2014) also studied the implementation of Lean's tools and techniques such as the 'Last Planner System' and concluded that Lean construction' practices couldn't be successfully operationalised without workers' commitment, pro-Lean attitudes, stakeholders' involvement, effective communication, supply chain coordination, and cross-department cooperation and collaboration.

Table 5: 12 - Barriers of Lean Construction

Factors	Strongly agree	Agree	Disagree	Strongly disagree	$\sum f$	$\bar{x}$	RII	Rank
Lack of management commitment	3	14	10	0	27	2.74	0.69	11th
Long implementation period	4	18	5	0	27	2.96	0.74	8th
Lack of proper training	13	12	1	1	27	3.37	0.84	3rd
Lack of adequate skills and knowledge	8	18	1	0	27	3.26	0.82	5th
Lack of application of the fundamental techniques	9	17	0	0	26	3.35	0.84	4th
Gaps in standards and approaches	4	17	5	0	25	3.08	0.77	7th
Fragmented nature of industry	8	9	7	1	26	2.85	0.71	10th
Cultural barriers	2	11	13	0	26	2.58	0.65	12th
Lack of implementation understanding and concepts	4	22	0	0	26	3.15	0.79	6th
Resistance to change	13	7	5	1	26	3.42	0.86	2nd
Government bureaucracy and instability	13	12	1	0	26	3.46	0.87	1st
Long list of supply chain and lack of trust	3	19	4	0	26	2.96	0.74	9th

Table 5: 13 - Enablers of Lean Construction

Factors	Strongly agree	Agree	Disagree	Strongly disagree	$\sum f$	$\bar{x}$	RII	Rank
Management commitment	4	22	0	0	26	3.15	0.79	6th
Good working environment	4	12	10	0	26	2.77	0.69	11th
Customer focus and integration	4	21	1	0	26	3.12	0.78	8th
Effective change management processes	8	17	0	0	25	3.32	0.83	4th

Regular training of workforce	12	13	1	0	26	3.42	0.86	1st
Effective planning	7	19	0	0	26	3.27	0.82	5th
Integration of teams and supply chains	11	14	1	0	26	3.38	0.85	2nd
Continuous improvement culture	3	22	1	0	26	3.08	0.77	9th
Benchmarking of suppliers against each other	4	12	10	0	26	2.77	0.69	12th
Communication and coordination between parties	11	15	0	0	26	1.6	3.42	13th
Review of performance towards targets	5	20	1	0	26	3.15	0.79	7th
Wide acceptance of Lean principles	10	15	1	0	26	3.35	0.84	3rd
Understanding of Lean benefits in construction project management	3	22	1	0	26	3.08	0.77	10th

5.3.6 Part 5: Lean Project Management and Performance

The last part of the questionnaire examined the link between Lean project management and construction performance using the 4-point Likert scale as seen in Table 5:14. It has been found that not only there's a link between Lean construction practices and performance, but also that Lean helps construction firms to improve their operational and business performances. Most of the participants also indicated that Lean project management is linked to their company's business strategy (*See* Table 5:15). The results indicate that 13 participants agreed and another 12 respondents strongly agreed that 'Lean project management enhances operational performance'. In fact, the link between Lean and the operational performance of construction firms was stressed by most of the participants. This was followed by 'Lean project management initiatives improve business performance' with which 22 participants agreed or strongly agreed as shown in Table 5:15.

Moreover, when asked about which stage of business strategy, Lean had the greatest impact, most of the respondents identified the "planning" and "execution" stages as the key areas of impact (*See* Table 5:16). The interviews' results also support this fact (*Refer* to Section 5.2.1). The interviewees indicated that the adoption of pro-Lean practices would help Saudi construction firms to overcome some of their operational challenges, especially if managers abandoned the use of "paper-based tools" and substituted them with real-time planning and control techniques such as Lean's Andon.

Numerous empirical studies have found a positive link between Lean construction's adoption and performance. For example, Li et al. (2019) assessed the impact of Lean construction's practices on construction firms' performance and found that Lean helped construction firms to make significant improvements in the areas of "quality, cost, time, safety and organisation in practice". Another study by Jünge et al. (2019) investigated the impact of Lean's principles on project planning and control processes. They found that Lean's adoption enabled firms to plan and control various project activities more effectively, which in turn helped to mitigate the risks of delays and cost overruns and that ultimately improved their overall performance. Moreover, Ma et al. (2018) studied the impact of Lean's practices on the performance of built-environment projects. They found that the adoption of Lean's techniques helped firms to "improve the productivity of the built environment", to substantially improve efficiency of production operations and to closely integrate supply chain operations.

Table 5: 14 - Lean Project Management and Performance

	Weighted frequency (f)							
Advantages	**Strongly agree**	**Agree**	**Disagree**	**Strongly disagree**	$\sum f$	$\bar{x}$	**RII**	**Rank**
Both constructs are very closely linked	6	14	8	0	28	2.43	0.61	4th
Lean project management is similar to the traditional practices	2	8	16	0	27	2.37	0.59	5th
Lean project management initiatives improve business performance.	5	17	5	0	27	3.00	0.75	2nd
Lean project management eliminates material waste in construction	7	11	9	0	27	2.93	0.73	3rd
Lean project management enhances operational performance	12	13	0	2	27	3.30	0.83	1st

Table 5: 15 - Lean Project Management and Business Strategy

Total respondents	**49**	**100%**
Yes	35	71.43
No	10	20.40
No response	4	8.16

Table 5: 16 - Lean project management and Stages of Business Strategy

Total respondents	**49**	**100%**
Initiation	10	20.41
Planning	15	30.61
Execution	12	24.50
Control	10	20.40
Other	2	4.08

5.4 Quantitative Data Validation

The quantitative data which had been collected as part of this research was analysed using statistical methods as shown in the previous sections. The outcomes of the data analysis processes had been shared with relevant personnel in the Binladin Construction Company / BCC for validation. The author received a confirmation email indicating that generally the results were consistent with the operational reality of the firm. Accordingly, the outputs of the quantitative data analysis processes have been used as a foundation for the design and development of a process map and Simio model for the company's operations.

5.5 Process Map Development

A process map has been developed for one of Binladin Construction Company / BCC's recent construction projects. The project consisted of numerous activities (*See* Figure 5:1), but this research focused primarily on six major activities; namely, framing, windows, electrical, elevators, drywall and exterior casework. The time and cost of these activities have been modelled using the Simio 10 simulation software. The simulation process required the author to incorporate further details into a process map to account for the variables that have an effect on the time and cost of the six activities; namely, worker cost per day, setup time, number of workers, processing time and suppliers' delay. This helped the author to identify the variables which had the greatest impact on the time and cost efficiencies of the construction activities under investigation. The process map shown in Figure 5:1 has been validated by experienced construction professionals who work for the case-study company (See Appendix III 11.4).

Figure 5:2 illustrates the critical paths of the construction project under investigation. It also demonstrates the interdependent nature of different activities and sheds light on the activities which project managers need to focus on in order to avoid unnecessary delays.

Table 5:17 outlines the different elements that make up a typical construction project at the case-study firm and describes what each element entails.

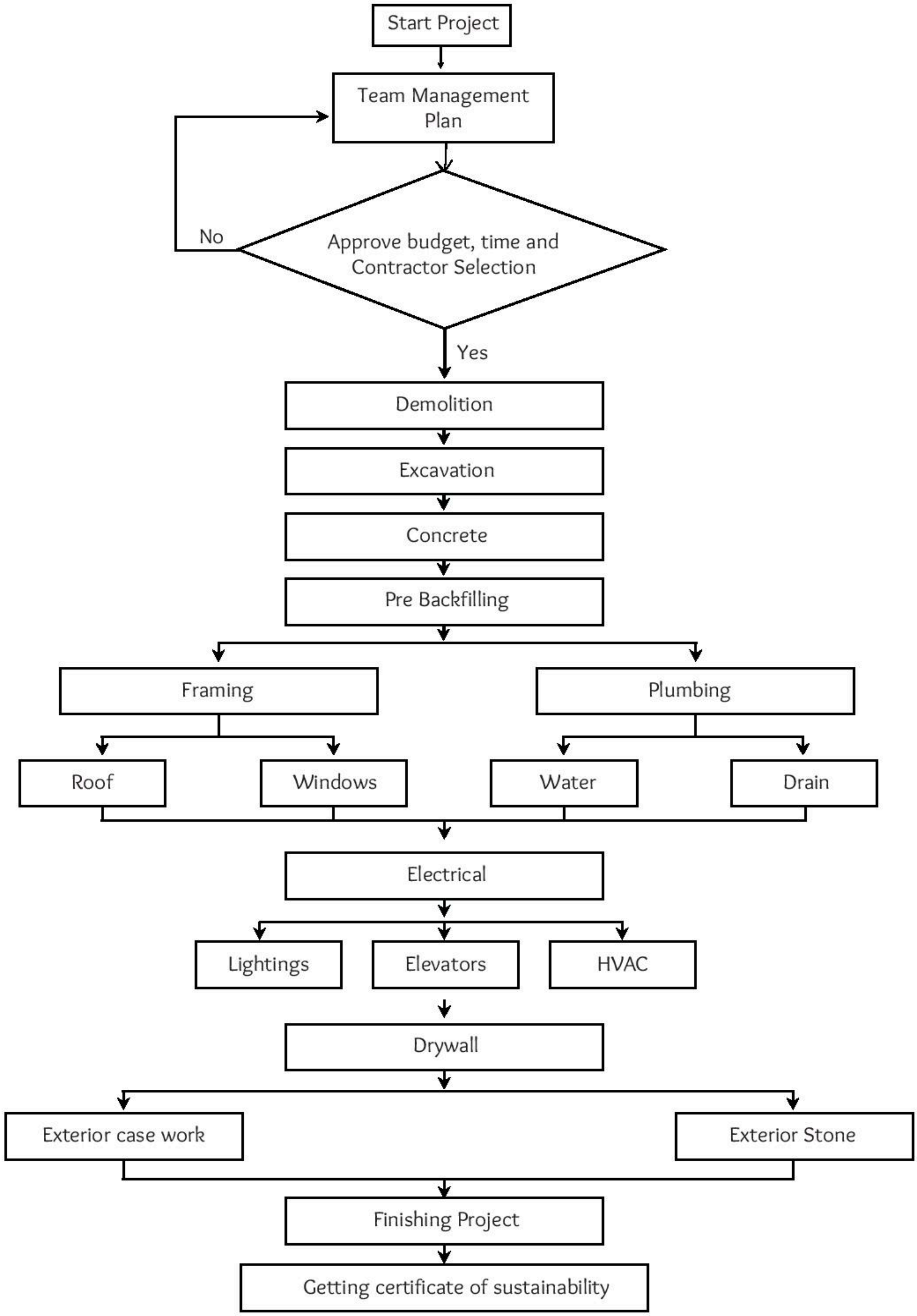

Figure 5: 1 - Process Map of Construction Activities

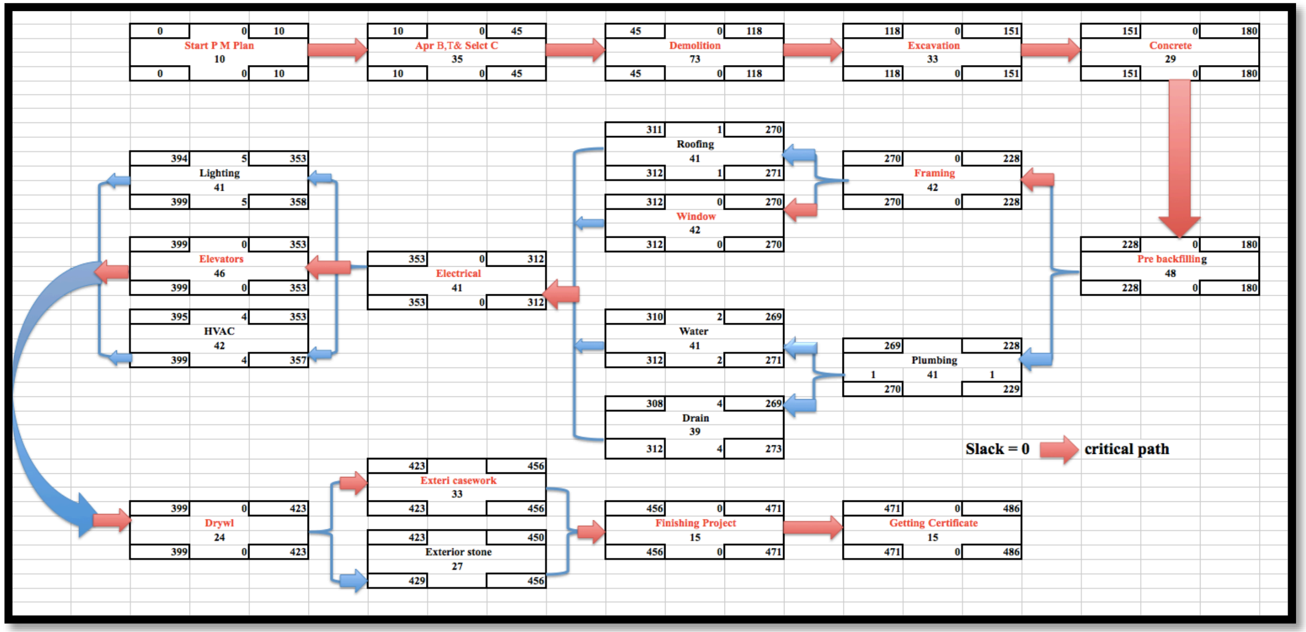

Figure 5: 2 - Map of Critical Paths of Construction Activities

Table 5: 17 - Key Elements in BCC's Construction Projects

Modelling Element Name	Type of Element	Element Time Requirement	Description
1. Start Project	Source	It takes 10 days to fully kick start a new construction project.	This is the first activity in a project's lifecycle. It reflects a project's initiation and getting the go ahead from senior management.
2. Team Management Plan	Process	It takes around 15 days for the management team to develop provisional plans and time schedules.	This is the second step in any construction project. It involves the development of initial plans for time and cost management. It also involves agreements about the resources needed to achieve a project's goals and identification of roles and responsibilities for different internal and external stakeholders.
3. Approval of Budget, Time and Selection of Suppliers	Decision	On average, it takes the firm 35 days to set budget, agree time schedules and select good suppliers.	This is another critical 'decision' activity which is concerned with reviewing the initial plans for time and cost management. In this activity plans are presented to senior managers, advisers and experts for scrutiny so that a decision for amendments or approval is made. It also involves decisions about the approval of key suppliers and contractors.
4. Demolition	Process	Typically, it takes around 73 days for demolition of average-sized buildings to be completed.	This activity is concerned with tearing down old buildings or structures to make way for the project under construction. Almost all projects involve this activity but in different forms and scales.
6. Excavation	Process	Excavation activities usually take around 33 days on average construction projects.	This activity involves the movement of soil, rocks and other materials mostly using heavy machineries. This activity is common in almost all construction projects. Firms can't bring up the foundations of their projects without making sure that the area is excavated and readied for construction to take place.
6. Concrete	Process	It takes the case-study firm around 29 days to finish the concrete work.	This activity involves the use of composite materials to build and/or support the structural foundations of a construction project. It often involves the use of cement, soil, gravel and water and other additives to create strong structures.
7. Pre Backfilling	Process	Pre backfilling activities take around 48 days	This activity involves putting soil back onto the foundations of a construction project once the 'concrete process' is over. This activity is more common in projects that involve 'excavation'.
8. Framing	Process	Framing activities (i.e. roofs and windows) take as long as 42	This activity is another critical project process. It involves putting together the structural architecture of a project. It requires firms to put together frames which can be in the form of wood, steel or concrete to give structure the necessary

		days to be completed	shape and support. The frames can be for roofs, windows or the entire building or structure depending on the project.
9. Plumbing	Process	It takes plumbers around 43 days to complete all their activities (i.e. water & drain) in average-sized construction projects.	This activity involves putting together systems of pipes and fixtures which facilitate the transfer of water (mostly drinking water) in the building as well as support th removal of waterborne wastes. This activity is concerned primarily with the construction of water supply and drain pipelines.
10. Electrical	Process	The electrical activities (i.e. Lightings, Elevators & HVAC) take around 41 days to be completed	This is one of the most critical activities in any construction project. It involves the wiring, assembly, installation of electrical systems. The systems can be lights, elevators or HVAC.
11. Drywall	Process	It takes, on average, 24 days to finish drywall activities (i.e. exterior stone and interior casework.	This is another critical construction activity. It is concerned with the use and application of drywalls onto the interiors of a building or construction site. It is different from the traditional walls which require the use of mortar and plasters. Almost all buildings' construction projects require the use of some form of drywall construction.
12. Finishing Project	Decision	Usually it takes around 15 days to finalise a project and hand it over to its owners.	This is a final 'decision' activity which signals the completion of a construction project. It involves thorough inspects and reviews of the constructed facilities particularly in terms of quality of finished structures and their compliance with pre-agreed specifications. This activity also involves handing over a constructed facility or building to its owners.
13. Getting Certificate of Sustainability	Process	It takes approximately 15 days for sustainability to be assessed and for certificates to be issued.	This is the very last step of contemporary projects. It involves application for, and acquisition of relevant certificates to confirm the sustainability of the constructed facility, structure or building. This is sometimes required by authorities, but it is sometimes used by construction firms to showcase their commitment to sustainability and to global industrial best practices.

5.6 Taguchi Data - Design of Experiments

There are numerous and various techniques out there which researchers and practitioners can use to design their experiments. These include, but not limited to: Latin hypercube, fractional factorial, randomised complete block design, central composite, response surface design, full factorial, optimal design, Plackett-Burman, full Box-Behnken, and Taguchi. The author has chosen Taguchi for this research for two main reasons; namely, its procedural simplicity and its applicability/relevance to the subject under investigation. The Taguchi technique is also different from other methods of design not only in terms of its processes and procedures, but also due to the uniqueness of its design concepts. For example, Taguchi is uniquely capable of blocking out the effects of environmental variations such as seasonal or daily fluctuations as well as other kinds of irrelevant noise. It is generally based on three core concepts, namely:

1. Quality is supreme priority and must be designed into products rather than inspected.
2. Products must have features that shield it from uncontrollable environmental factors and should be designed with minimal deviations from pre-defined targets.
3. Cost of quality must be measured and considered as a 'function of deviation'.

Principally, Taguchi encourages continuous quality improvement. Basically, it assumes that improvement of a product's quality is an ongoing effort and must be pursued tirelessly. It also assumes that optimal quality is achieved when all variations and/or deviations from the main pre-defined targets are eliminated. Hence, it requires designers to concentrate all their efforts on the development of products that are insensitive to noise factors and deviate as little as possible for the desired target values. In order to do this, Taguchi enables designers to use "orthogonal arrays" (OA) to design their experiments. QA's are specialist tables constructed specifically for the product or project under development to help designers account of all the issues that are concerned with their design. The tables provide designers with consistent and easy means of designing reliable and robust experiments.

5.6.1 Deployment of the Taguchi Technique

There are several steps that a designer has to take and four phases of design that a product, process or project has to go through in order to fulfil the requirements of Taguchi. Generally the process starts with a good understanding of the operational and procedural fundamentals of construction projects and identification of critical process parameters for experimentation. In Taguchi, the main factors are divided into two broad categories; namely:

1. Control factors which refer to variables that can be brought under the control when needed and if necessary.
2. Noise factors which refer to variables that are beyond the control of practitioners in real-life projects, but may be controlled by designers in laboratory experiments.

The quality optimisation process of Taguchi consists of four core phases; namely:

1. Phase 1: identification of quality characteristics and key process/product parameters.
2. Phase 2: design and execution of experiments sequence

3. Phase 3: statistical analysis of variables and identification of optimum conditions.
4. Phase 4: validation/confirmation of experiments using the optimum conditions.

In more detail, the first phase of Taguchi requires the designer to: identify the key factors for optimisation; determine analysis conditions; identify control factors and their levels; design a set of matrix experiments or orthogonal arrays (QA); and define the data analysis procedures. In the second phase, designers need to perform the designed experiments based on predefined conditions. In the third phase, designers need to: examine the data; identify optimal control factor levels; and predict performances. In the last phase, the designers need to validate and verify their experiments using the newly-identified optimal conditions. The author performed each of these steps effectively and generated all the necessary information concerning the use of Kanban's 6 rules by Binladin Construction Company.

The author specified the main control and noise factors for each of the construction activities under study in order to prepare the Taguchi tables. The tables comprise of three levels based on the primary data acquired from the case-study organisation. The development of the tables was essential to create the Taguchi Arrays needed to run the Simio 10 simulation model. The tables initially comprised of many factors or parameters that had an effect on the construction activities under investigation. Taguchi enabled the author to minimise the number of factors using the 'loss function' and to focus primarily on the target performance. In order for process quality to satisfy senior managers' performance expectations, Taguchi inclined the author to focus his attention on reducing suppliers' delays, avoiding overprocessing, shortening setup time, reducing workers' cost per day and optimising workers' numbers. Generally, most of the identified factors are controllable variables with exception of suppliers' delays which may be caused by uncontrollable incidents, events or circumstances like the Coronavirus pandemic. Examples of non-controllable factors include: severe weather conditions or national disaster, sudden machine breakdown and political instability (e.g. Labour strikes). These factors impact on the productivity of construction teams, but there isn't a lot manager can do to prevent them or mitigate their risks. Taguchi enabled the author to only develop 'orthogonal arrays' for the controllable factors in three different levels - low, average and high. The idea is to develop a high quality design that's not affected by noise (i.e. Irrelevant disruptive factors) and improve it continually. Taguchi tables comprise an element called degrees of freedom or DoF. Counting the DoF's enables the designers to identify the minimum number of experiments they must run in order to gauge the real impact of the variables or factors under study on the process or product being designed.

The Taguchi Tables 5.18 - 5.26 have been created based on real-life scenarios and data from the case-study organisation. Table 5:18 show the 'project team management plan' activity with one factor (processing time) and three levels (high, average and low). The table indicates that it takes on average 10 days for a construction project team to prepare the initial project management plans. Table 5:19 shows the time it takes to complete the 'budget, time and contractor selection approval' activity. It also consists of a factor (processing time) and three levels. The table shows that it takes, on average, 35 days to complete this particular activity.

Table 5: 18 - Project Team Management Plan (SPTMP)

Factor Name	High	Average	Low
Processing Time (Day)	14	10	7

Table 5: 19 - Approve Budget, Time and Contractor Selection

Factor Name	High	Average	Low
Processing Time (Day)	42	35	28

Moreover, Table 5:20 and Table 5:21 show the factors that affect the time and cost it takes to complete 'framing' and 'windows' construction activities. Both tables comprise of five factors and three levels. The tables also indicate that it will take, on average, 42 days for each of the activities to be completed by the relevant teams. These estimates are based on the experiences and assumptions of the case-study firm's project/operations managers.

Table 5: 20 - Framing

Factor Name	High	Average	Low
Worker Cost per Day (SR)	300	250	200
Processing Time (Day)	40	30	20
Setup Time (Day)	3	2	1
Number of Workers (Person)	5	4	3
Supplier's Delays (Day)	15	10	7

Table 5: 21 - Windows

Factor Name	High	Average	Low
Worker Cost per Day (SR)	300	250	200
Processing Time (Day)	40	30	20
Setup Time (Day)	3	2	1
Number of Workers (Person)	5	4	3
Supplier's Delays (Day)	15	10	5

Similarly, Tables 5.22 - 5.25 show the time, cost and number of people it takes to complete the electrical, elevators, drywall and exterior casework construction activities. The Table 5:22 indicates that it will take around 41 days, on average, for electrical activities to be completed and cost around 250 SR per day for manpower. Table 5:23 shows that it will take, on average, around 46 days for the 'elevators' activity to be completed and cost at least 200 SR per day for workers. In contrast, it takes much fewer days to finish the 'drywall' construction activity. Table 5:24 shows that it can take, on average, 24 days for dry walls to be installed and cost as high as 350 SR for workforce expenses. On the other hand, it takes, on average, around 33 days for the relevant project teams to complete the 'exterior casework' activity as shown in Table 5:26. The table also shows that it can cost up to 250 SR per day for workers to install and finalise the 'exterior casework' activity.

Table 5: 22 - Electrical

Factor Name	High	Average	Low
Worker Cost per Day (SR)	300	250	200
Processing Time (Day)	40	30	20
Setup Time (Day)	3	2	1
Number of Workers (Person)	5	4	3
Supplier's Delays (Day)	12	9	6

Table 5: 23 - Elevators

Factor Name	High	Average	Low
Worker Cost per Day (SR)	300	250	200

Processing Time	(Day)	40	30	20
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	21	14	7

Table 5: 24 - Drywall

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	350	300	250
Processing Time	(Day)	18	15	12
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	10	7	5

Table 5: 25 - Exterior Casework

Factor Name		High	Average	Low
Workers Cost per Day	(SR)	250	200	150
Processing Time	(Day)	20	15	10
Setup Time	(Day)	10	8	6
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	14	10	7

Last but not least, Table 5:26 shows that the final project activity (i.e. finishing project) is affected by only one factor; namely, processing time. The table shows that it may take as few as 12 days and as high as 18 days to finalise a project and hand it over to its owners.

Table 5: 26 - Finishing Project

Factor Name		High	Average	Low
Processing Time	(Day)	18	15	12

5.7 Project Process Mapping – Linking Data to Simulation Model

The previous sections demonstrate how the different construction activities relate and connect with each other (*refer* to Figure 5.1 and Figure 5.2). They also outlined the different variables or factors which are believed to affect the cost and time efficiencies of the six activities under investigation. They highlighted the nature of relationships that exist between the two sets of variables. More importantly, the latter sections Taguchi's technique has been used to design experiments which are essential in order for the author to develop, test, and verify a discrete event simulation (DES) model. The data from the Taguchi's tables (i.e. the orthogonal arrays) has been transferred onto Simio 10 software to create and simulate the entire process shown in Figure 5.1, but with a focus on the six construction activities shown in Tables 5.18 - 5.26. The model relied on 54 scenarios which are based on real-life experiences of the case-study firm and also with the knowledge and expertise of Binladin Construction Company / BCC's employees and managers. Figure 5:3 demonstrates the steps/process that the author followed in order to assess the current state of the case-study firm's operational performance, to identify areas of improvement and also to device practical and reliable improvement strategies.

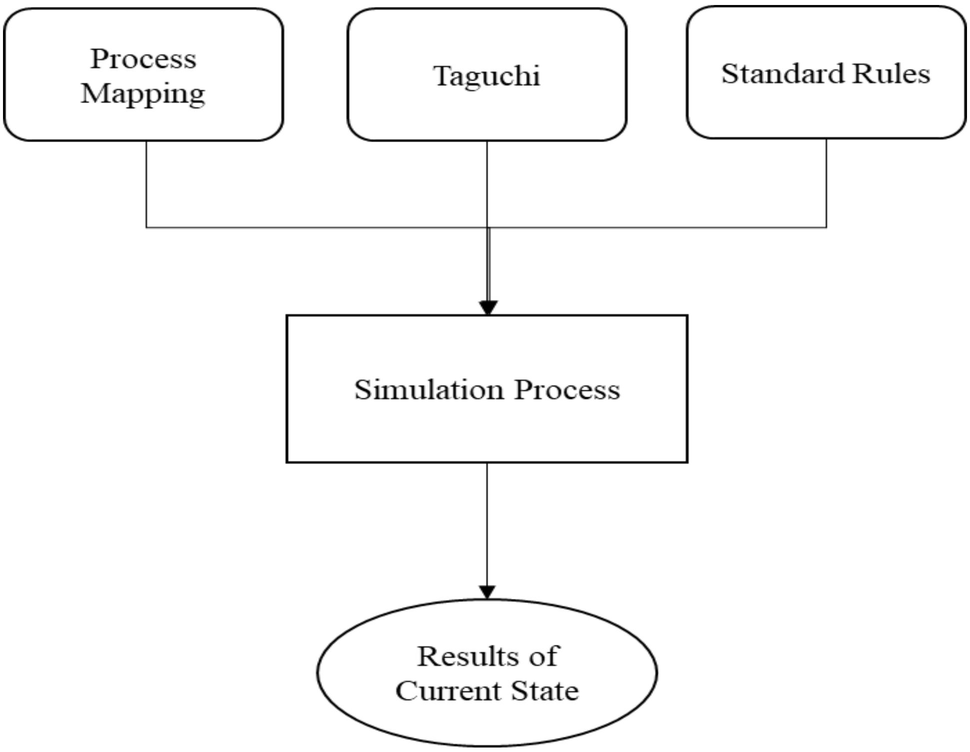

Figure 5: 3 - Current State of Simulation Model Flow Chart

5.8 Summary

This chapter presented the outcomes of data analysis and interpretation processes. The data from the interviews was analysed using thematic analysis which helped to identify several important themes. First, the participants claimed that their company's operational performance would improve significantly if managers abandoned the use of "paper-based tools" in favour of real-time planning and control techniques. There were significant planning and control deficits between the case company's current performance and that of international construction firms. For example, the company's failure to establish close relationships with its supply chain partners puts a "strain on schedules" and also hindered its ability to streamline its procurement operations. Second, it has been found that traditional practices offer construction firms with good means of controlling costs and reducing the risk of delays, but they aren't effective in dealing with contemporary operational challenges of the construction industry. In fact, it has been found that traditional project management practices hinder management's ability to account for all project risks, to coordinate construction activities effectively, to allocate resources efficiently and most importantly to prevent time and cost overruns.

Third, employees of the case's firm have been found to have a positive attitude towards Lean and supported the idea of using Lean management practices to help project managers to reduce costs and improve quality. The participants often associated Lean with improvements in operational efficiency, management effectiveness and most crucially with cost savings. It appears that their perceptions are shaped by Lean's positive contributions to the company's performance, such as better communication, closer collaboration, fewer defects, improved quality, stronger stakeholder relationships and most importantly greater bottom-line results.

Fourth, the interviews highlighted a variety of benefits which encouraged the case company to embrace the principles of Lean construction. The identified benefits included: greater value for money; greater returns on investment; improved quality; improved operational efficiency; reduced cost; higher client satisfaction levels; improved public image; and most importantly reduced disruptions and unnecessary delays. Fifth, the interviews also highlighted numerous enablers and facilitators of Lean construction. Most of the interviewees think that the success of any Lean construction initiative depends heavily on senior management's commitment and motivation to allocate the needed resources and the right personnel to implementation projects.

Sixth, the interviews also highlighted several challenges and barriers that the case company had faced during the implementation and operationalisation of pro-Lean practices. These included: cultural resistance, short-sighted investment policies, lengthy implementation timeline, costly implementation processes, managers' impatience, lack of knowledge and skills, complexity and lack of workers' buy-in. Senior managers' short-sighted investment policy has been identified as a significant barrier to Lean construction practices.

Quantitative analysis of questionnaire data also revealed the perceived impact, benefits, implications and implementation barriers of Lean construction. In terms of benefits, the participants strongly agreed that Lean would help construction firms to: eliminate waste and non-value adding activities; solve constructability problems; and aid effective communication in teams. The participants also indicated that Lean helped their firm to: reduce lead-time and cost; help in standardisation of activities; and improve safety and environmental performance. In terms of impact on organisational management, most of the respondents appeared to believe that Lean initiatives would enable their firms to: motivate employees and shape their behaviours; integrate supply chain; and increase staff awareness of organisational problems. They also indicated that Lean's practices had helped their company to reduce "energy consumption", reduce "waste" and improve staff's participation in decision-making processes.

In terms of barriers and enablers of Lean construction, most of the participants indicated that government bureaucracy; resistance to change; lack of training and ineffective deployment of fundamental techniques were the main barriers to successful adoption and implementation of Lean's principles. On the other hand, the participants indicated that regular training of staff; integrated supply chains; and effective change management processes were significantly important for the success of Lean construction initiatives.

The chapter also demonstrates the Taguchi technique has been used to design experiments and to support the development of a simulation model that reflects the real-life experiences of Binladin Construction Company with the management of the time and cost efficiencies of six key construction activities; namely, framing, electrical, elevators, drywall, windows and exterior casework. It also demonstrates how the primary data have been linked to the Simio 10 simulation model.

Chapter 6: Assessment of Current State

6.1 Introduction

This chapter presents and discusses the outputs of an assessment of the current state of the operational performance of the Binladin Construction Company / BCC. The author used the Minitab software to organise and analyse the relevant data. ANOVA analysis in particular has been used to explore the nature of relationships between six key construction activities (framing, windows, electrical, elevators, drywall and exterior case work) on one hand and five performance indicators (worker cost per day, processing time, setup time, number of workers, and delays) on the other hand. ANOVA analysis enabled the author to assess the statistical significance of the relationships between the two sets of variables.

6.2 Differences and Similarities between Manufacturing and Construction

There are numerous differences and few similarities between the manufacturing industry and the construction industry, which make the employment of Lean's tools and techniques such as Kanban difficult not only in terms of implementation, but also in terms of understanding the significance of their impact and their operational implications. In terms of similarities, both manufacturing and construction firms produce tangible products whose quality can't be too difficult to examine, monitor and control. Also, both industries' performance, especially in terms of operational performance is affected by the characteristics of the workforce. This means that changes in workers' behaviours and personnel management policies can have significant impact on a wide range of performance indicators such as productivity and product quality. Moreover, the concept of 'value' is somewhat the same in both industries. Manufacturers and construction firms view 'value' as a reflection of their abilities to meet their customers' pre-defined set of specifications and expectations (i.e. ultimate value is delivered when customers are highly satisfied with a product's tangible and intangible characteristics/specifications).

However, construction operations are often far less standardised than manufacturing activities and that makes it difficult to apply Lean's principles to construction firms, especially since the philosophy relies heavily on standardisation of processes as a quality management strategy. Also, construction, operations typically take place outdoors and involve movement of large machineries and specialist equipments, whereas manufacturing operations often take place in specialist, dedicated facilities that are designed to facilitate the production of single or various models of a particular product. More importantly, manufacturing operations are characterised by continuity and predictability, whereas construction firms more often than not work on one-off projects or prototypes. Hence, construction firms' operations are characterised by a high degree of dynamism, unpredictability and discontinuity.

6.3 Simulation Model: Discrete Processes

The author has used Minitab to analyse the current state of Binladin Construction Company's operational performance. The necessary input data were collected directly from the case study firm through discussions with its staff, observations and review of archival documentations. Some data were estimated based 'reported' values in other empirical studies that investigate the impact of Kanban on firms' operational performance. Once the necessary inputs had been collected, organised and prepared for use, the specialist function of 'Orthogonal Arrays' in the Minitab program was used - this involved setting the noise factors as an 'external array' and the control factors as an 'internal array'. In general terms, control factors refer to controllable which are typically used to improve processes, while noise factors are concerned with the variables that are beyond the control and that have an impact on a system's performance.

Minitab enabled the author to produce graphical outputs which explain the relationship nature of different variables (*See* Figures 6:1 - 6:10 below). It is important to note that the way lines lay in the graphs define the nature of the relationship between variables. For example, if the line lies in a horizontal state and parallel to the x-axis, it means that there is no correlation between the variable and the main construct. This is the case for the relationship between 'time of framing' and 'worker cost per day' in Figure 6:1. On the other hand, if the line does not lie horizontally or somewhat close to a horizontal state, it means that there is a correlation between the main construct and the variable. The more vertical the line is, the stronger the relationship is. In other words, the strength of the correlation is determined by the sharpness of the lines produced in the Minitab graphs. For example, there is a strong correlation between 'processing time' and how much time 'framing' takes. This correlation is even stronger than the effect of 'delay' on framing time (*Refer* to Figure 6:1). Basically, the output of the simulation model has helped the author to understand how the case-study firm may create or optimise the 'value' it provides to its clients. End-to-end value is typically created, in a Lean's system of management, through identification and elimination of non-value-adding activities and waste. For example, in the context of the construction industry, over-processing and waiting time are two examples of waste which undermine construction firms' abilities to deliver optimal value.

6.4 Simulation Procedure

To assess the nature of relationships between the different variables, the author has followed several important steps to produce the necessary outputs. First, the author has had to use the SIMIO 10 software to process the raw data. The outputs from the software were then inputted manually into the Minitab program. Second, the program was set up to produce the necessary 'main effect' plots for the variables and the main constructs. Basically, the Minitab program was used to plot the signal-to-noise effects and produce graphic outputs. It is important to note that the outputs of Minitab can't be easily understood in isolation. Users must interpret them in conjunction with other tools such as MANOVA (Multi-factor Analysis of Variance) and the more popular ANOVA analysis. There are small differences between MANOVA and ANOVA. Both tools are typically used to conduct one-way variance analysis, but MANOVA is more commonly used to analyse multiple factors. Hence, MANOVA is often used when a research, construct is affected or influenced by more than one factor or variable. Generally, both MANOVA and ANOVA are employed by researchers who are trying to identify and study the differences between means through systematic analysis of variances between group means and by examining how different variables interact with each other. Accordingly, the design of the Kanban Orthogonal Array in Minitab resulted in a good-sized sample of 54 different scenarios. The distribution of factors was based on the total number of variables.

Third, the author has used the state program (a statistical program) to identify and evaluate the statistical variances. In particular, he used an extension of two-way ANOVA, which had enabled him to better understand how multiple independent variables relate to or interact with a continuous dependent variable. He considered the use of 'factorial ANOVA' instead of the MANOVA due to the fact that the use of Minitab to calculate the signal-to-noise ratios restrict the use of statistical post-estimation methods.

The Minitab analysis was based on the following assumptions:

- ❖ Dependent variables should be measured using a 'continuous level' setup
- ❖ All independent variables (factors) are fitted into multiple levels (categories) and comprise of variables from different, unrelated groups. In order to satisfy this assumption, the author categorised the Kanban factors as 1, 2 and 3.

- All factors must have the independence of observation.
- There should be no significant outliers.
- Dependent variables should be distributed across groups and factor compositions.

The author has had his attention focused primarily on understanding the efficiencies of six construction activities; namely, framing, windows, electrical, elevators, drywall and exterior casework. Accordingly, the cost and time each of these activities take have been estimated using three categories - high, average and low (*Refer* to Tables 6:1 - 6:4).

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	300	250	200
Processing Time	(Day)	40	30	20
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	15	10	7

Table 6: 1 - Framing

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	300	250	200
Processing Time	(Day)	40	30	20
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	15	10	5

Table 6: 2 - Windows

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	300	250	200
Processing Time	(Day)	40	30	20
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	12	9	6

Table 6: 3 - Electrical

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	300	250	200
Processing Time	(Day)	40	30	20

Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	21	14	7

Table 6: 4 - Elevators

Factor Name		High	Average	Low
Worker Cost per Day	(SR)	350	300	250
Processing Time	(Day)	18	15	12
Setup Time	(Day)	3	2	1
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	10	7	5

Table 6: 5 - Drywall

Factor Name		High	Average	Low
Workers Cost per Day	(SR)	250	200	150
Processing Time	(Day)	20	15	10
Setup Time	(Day)	10	8	6
Number of Workers	(Person)	5	4	3
Supplier's Delays	(Day)	14	10	7

Table 6: 6 - Exterior Casework

6.4.1 Analysis of Framing Actual Time

In order to examine the nature of the relationship between framing actual time on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand, the author performed a four-way factorial ANOVA using 54 scenarios which had been imported into Minitab from the Simio 10 software. The analysis process produced P-values for all of the independent variables which were then used to determine whether the correlation between the dependent variable (i.e. framing actual time) and other independent variables were statistically significant or not. Independent variables with P-values of less than 0.05 are considered to have a statistically significant impact on the dependent variable. Also, P-values of less than 0.001 indicate 'highly statistically significant' impact/correlation. For example, the ANOVA variance analysis for framing actual time shows that processing time, setup time and suppliers' delay all have statistically significant impact on actual framing time with P-values of 0.000. However, the actual framing time appears to correlate more strongly with processing time than with suppliers' delay and set up a time. In fact, its correlation with the setup time doesn't appear to be sharp enough (*See* Table 6:7 and Figure 6:1). All of the other independent variables don't appear to have a statistically significant impact on actual framing time. The P-values for both 'worker cost per day' and 'number of workers' were found to be higher than 0.05, with each recording a P-value of 0.191.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	0.59	0.3	1.72	0.191
Processing Time	2	3560.26	1780.13	10333.65	0.000
Setup Time	2	37.59	18.3	107.21	0.000
Number of Workers	2	0.59	0.3	1.72	0.191
S DELAY	2	612.93	307.46	1779.02	0.000
Total	53	4218.37			

Table 6: 7 - Analysis of Variance for Framing Actual Time

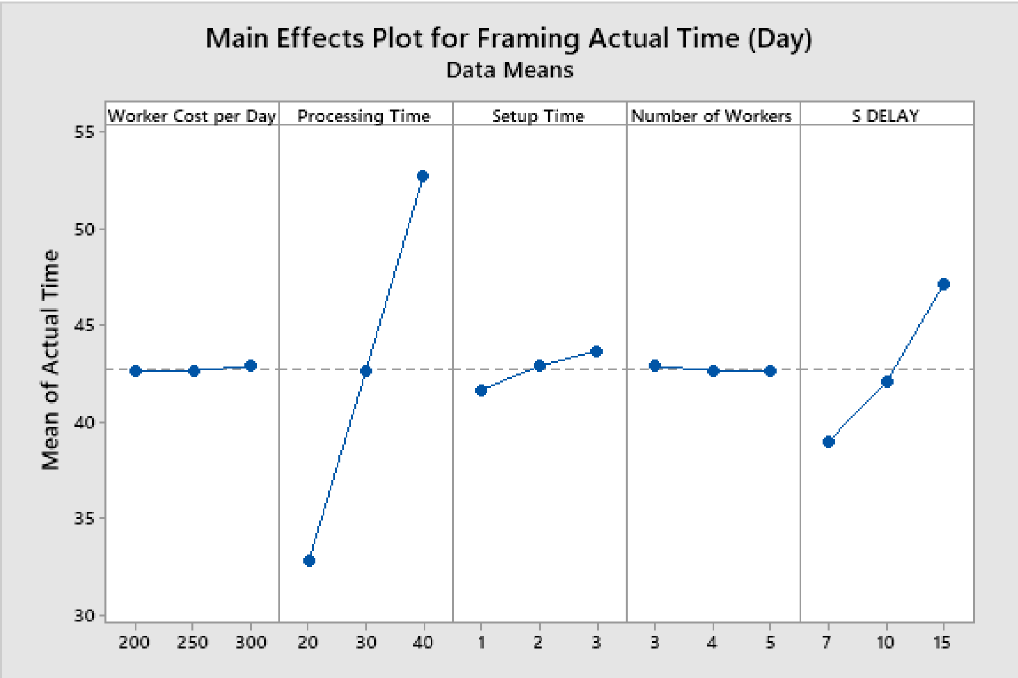

Figure 6: 1 - Main Effects Plot for Framing Actual Time (Day)

6.4.2 Analysis of Framing Actual Cost

The ANOVA variance analysis for framing actual cost shows that the worker cost per day, processing time, number of workers and suppliers' delay all have statistically significant impact on actual framing cost with P-values of 0.000. However, the actual framing cost appears to correlate more strongly with a number of workers than with the other variables. In fact, its correlation with the suppliers' delay doesn't appear to be as sharp as with the number of workers and processing time (*See* Table 6:8 and Figure 6:2). The only independent variable that doesn't appear to have a statistically significant impact on actual framing cost is 'setup time' which isn't surprising considering that the framing activity does not involve the use of heavy machineries whose setup times may be long and costly. The P-values for 'setup time' was found be 0.107 - a lot higher than the cutoff value of 0.05.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	2722322500	1361161250	148.2	0.000
Processing Time	2	3200747500	1600373750	174.25	0.000
Setup Time	2	43352500	21676250	2.36	0.107
Number of Workers	2	3632732500	1816366250	197.76	0.000
S DELAY	2	623320000	311660000	33.93	0.000
Total	53	10617408750			

Table 6: 8 - Analysis of Variance for Framing Actual Cost

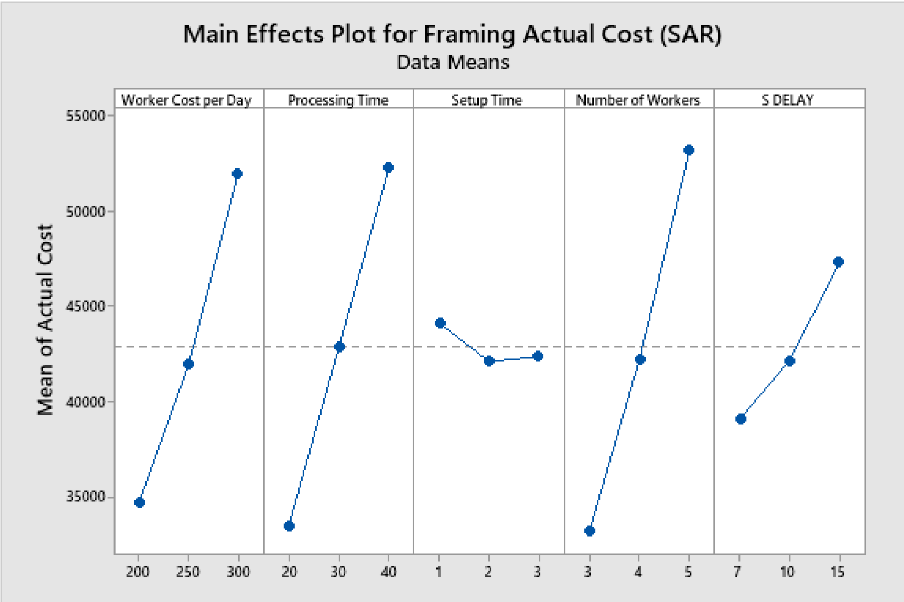

Figure 6: 2 - Main Effects Plot for Framing Actual Cost (SAR)

6.4.3 Analysis of Windows Actual Time

The ANOVA variance analysis for windows actual time shows that processing time, set up time and suppliers' delay all have statistically significant impact on windows actual time, but the windows time appears to be affected more strongly by processing time and suppliers' delay than by setup time. The first two variables recorded P-values of 0.000, whereas setup time recorded a P-value of 0.001 (*See* Table 6:9). Also, a closer examination of Figure 6:3 reveals that the relationship between the main construct and 'processing time' is a lot sharper than with the other variables. Interestingly, the worker cost per day and number of workers don't appear to have a statistically significant impact on actual windows time. It is not clear why it turned out that way. The P-values for worker cost per day and number of workers were found to be 0.376 which is a lot higher than the cutoff value of 0.05 for statistical significance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	4.48	2.24	1	0.376
Processing Time	2	3384.48	1692.24	755.21	0.000
Setup Time	2	40.48	20.24	9.03	0.001
Number of Workers	2	4.48	2.24	1	0.376
S DELAY	2	1014.48	507.24	227.37	0.000
Total	53	4544.76			

Table 6: 9 - Analysis of Variance for Windows Actual Time

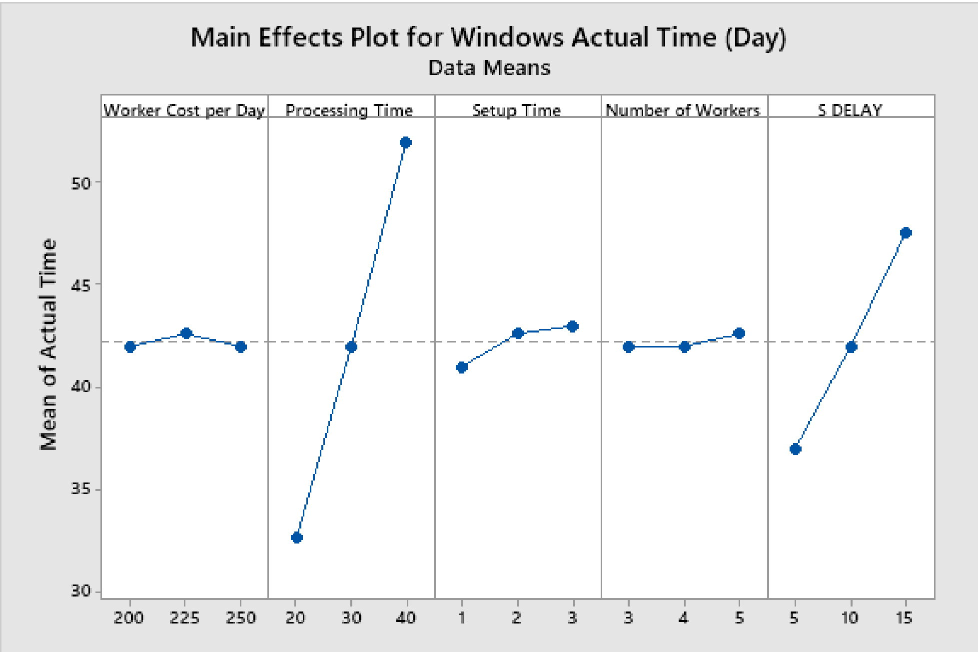

Figure 6: 3 - Main Effects Plot for Windows Actual Time (Day)

6.4.4 Analysis of Windows Actual Cost

The ANOVA variance analysis for windows actual cost shows that worker cost per day, processing time, number of workers and suppliers' delay have statistically significant impact on windows actual cost, but the construct appears to be affected more strongly by processing time and number of workers than by worker cost per day and suppliers' delay despite having the same P-values of less than 0.000 (*See* Table 6:10). Also, a closer examination of Figure 6:4 reveals that the relationship between the main construct and 'processing time' is a lot sharper than with all the other variables. On the other hand, setup time doesn't appear to have a significant enough impact on actual windows cost despite its P-value falling within the

0.05 cutoff value of significance. Precisely, the P-value of 'setup time' was found to be 0.021. This means that setup time has a statistically significant relationship with actual windows cost, but the relationship isn't as strong as the other variables. This is perhaps because the activity of windows' construction doesn't involve the use of complex machineries whose setup takes a lot of time and costly undertakings.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	636463573	318231787	55.53	0.000
Processing Time	2	2825094406	1412547203	247.47	0.000
Setup Time	2	48539240	24269620	4.23	0.021
Number of Workers	2	3336688990	1668344495	291.1	0.000
S DELAY	2	795985781	397992891	69.44	0.000
Total	53	7889211480			

Table 6: 10 - Analysis of Variance for Windows Actual Cost

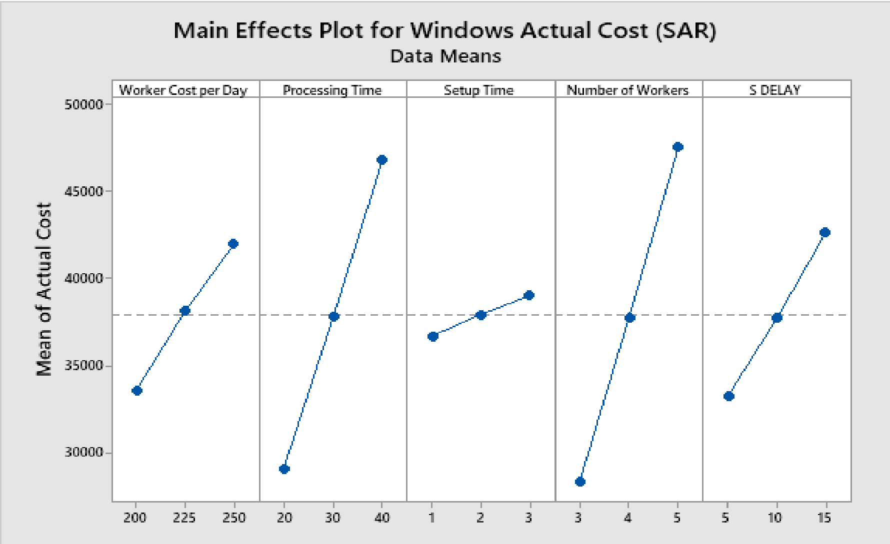

Figure 6: 4 - Main Effects Plot for Windows Actual Cost (SAR)

6.4.5 Analysis of Elevators Actual Time

The ANOVA variance analysis for elevators actual time shows that processing time, setup time and suppliers' delay all have statistically significant impact on actual elevators time with P-values of 0.000. However, the actual elevators time appears to correlate more strongly with processing time than with suppliers' delay and set up time. In fact, its correlation with the setup time doesn't appear to be sharp enough (*See* Table 6:11 and Figure 6:5). The other two independent variables don't have a statistically significant impact on elevators time. The P-values for both 'worker cost per day' and 'number of workers' were found be higher than 0.05, with each recording a P-value of 0.380.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	0.04	0.02	0.99	0.380
Processing Time	2	3567.72	1783.86	96712.37	0.000
Setup Time	2	37.05	18.03	977.26	0.000
Number of Workers	2	0.04	0.02	0.99	0.380
S DELAY	2	1738.43	869.21	47124.56	0.000
Total	53	5367.98			

Table 6: 11 - Analysis of Variance for Elevators Actual Time

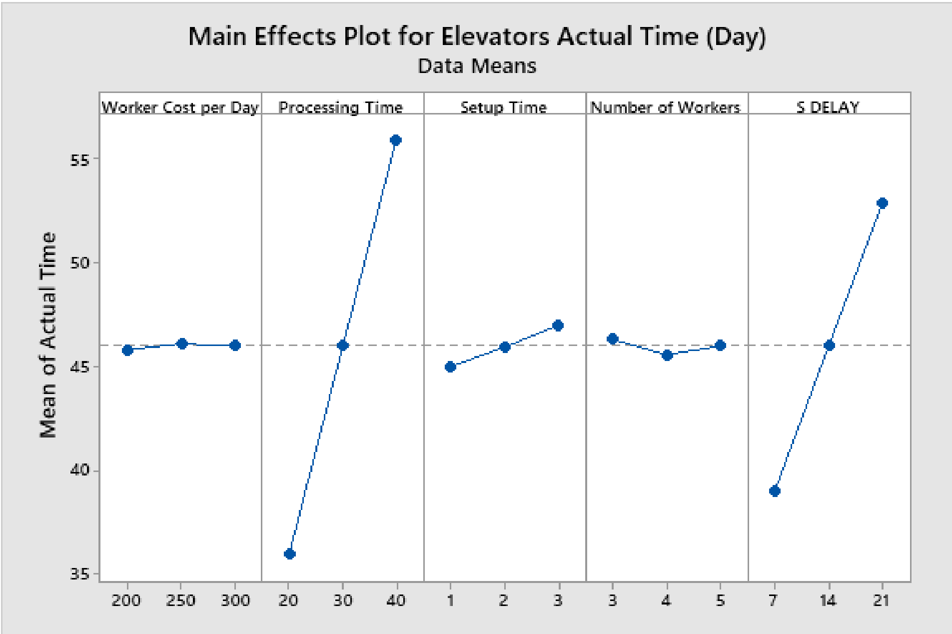

Figure 6: 5 - Main Effects Plot for Elevators Actual Time (Day)

6.4.6 Analysis of Elevators Actual Cost

The ANOVA analysis of variances for elevators actual cost shows that all of the independent variables have statistically significant relationship with elevator actual cost with P-values of less than 0.05. The worker cost per day, processing time, number of workers and suppliers' delay were all found to have P-values of 0.000. Setup time has a P-value of 0.044. Notably, the actual elevators cost appears to correlate more strongly with number of workers and worker cost per day than with the other variables. In fact, its correlations with the suppliers' delay and setup time don't appear to be as sharp as in the other variables (*See* Table 6:12 and Figure 6:6). It isn't quite so surprising at all that the 'setup time' variable turned out to have the least significant impact on elevators actual cost considering that the activity of elevator construction or installation doesn't necessarily or rarely involve the use of heavy machineries whose setup times may be long and costly.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	2910121496	1455060748	115.86	0.000
Processing Time	2	3697961668	1848980834	147.23	0.000
Setup Time	2	84430879	42215439	3.36	0.044
Number of Workers	2	4963833133	2481916566	197.63	0.000
S DELAY	2	1707888729	853944365	68	0.000
Total	53	14083778704			

Table 6: 12 - Analysis of Variance for Elevators Actual Cost

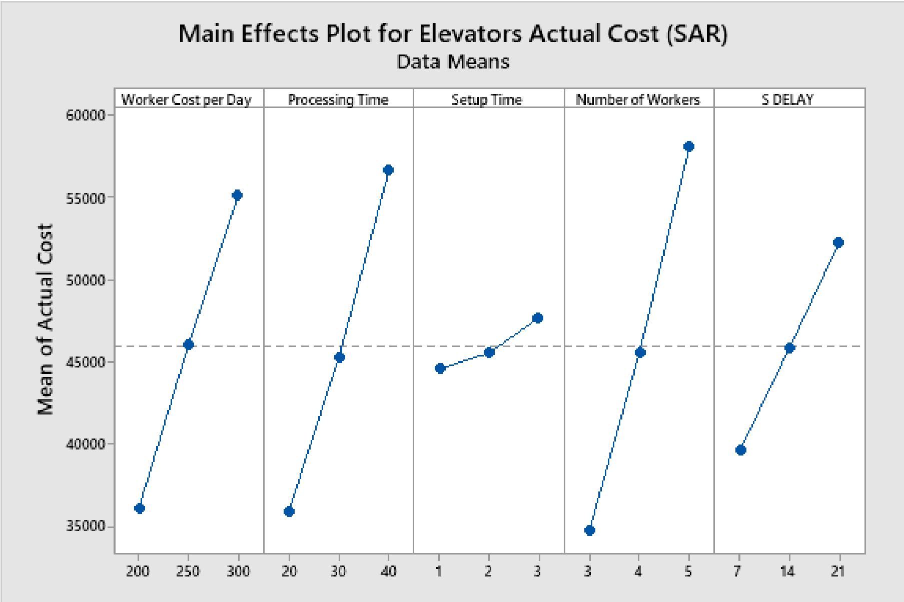

Figure 6: 6 - Main Effects Plot for Elevators Actual Cost (SAR)

6.4.7 Analysis of Electrical Actual Time

The ANOVA variance analysis for electrical actual time shows that processing time, set up time and suppliers' delay all have statistically significant impact on electrical actual time, but the electrical time appears to be affected more strongly by processing time than by suppliers' delay and setup time despite all of them having P-values of 0.000 (*See* Table 6:13). Also, a closer examination of Figure 6:7 reveals that the relationship between the main construct and 'processing time' is a lot sharper than with the other variables. Interestingly, worker cost per day and number of workers don't appear to have a statistically significant impact on actual electrical time. It is not clear why it turned out that way. The P-values for worker cost per day and number of workers were found to be 0.376 which is a lot higher than the cutoff value of 0.05 for statistical significance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	0.93	0.46	1	0.376
Processing Time	2	3500.93	1750.46	3781	0.000
Setup Time	2	37.93	18.46	39.88	0.000
Number of Workers	2	0.93	0.46	1	0.376
S DELAY	2	354.93	177.46	383.32	0.000
Total	53	3914.54			

Table 6: 13 - Analysis of Variance for Electrical Actual Time

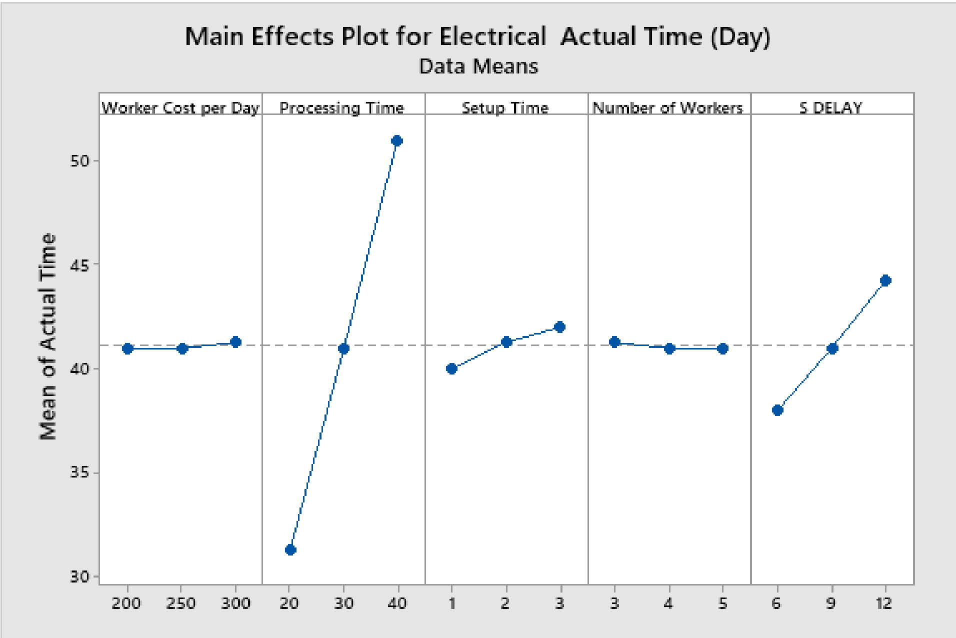

Figure 6: 7 - Main Effects Plot for Electrical Actual Time (Day)

6.4.8 Analysis of Electrical Actual Cost

The ANOVA variance analysis for electrical actual cost shows that worker cost per day, processing time, number of workers and suppliers' delay have statistically significant impact on electrical actual cost, but the construct appears to be affected more strongly by processing time and number of workers than by worker cost per day and suppliers' delay despite having the same P-values of less than 0.000 (*See* Table 6:14). Also, a closer examination of Figure 6:8 reveals that the correlations between the main construct and 'processing time' and 'number of workers' are a lot sharper than with all the other variables. On the other hand, setup time doesn't appear to have a statistically significant impact on actual electrical cost as its P-value is higher than the 0.05 cutoff value of significance. Precisely, the P-value of 'setup time' was found to be 0.095. This means that setup time has a relationship with actual electrical cost, but the relationship isn't significant enough. This is perhaps because the activity of electrical installations doesn't involve the use of complex machineries whose setup takes a lot of time or costs a lot of money.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	2580017500	1290008750	134.99	0.000
Processing Time	2	3183797500	1591898750	167.58	0.000
Setup Time	2	47627500	23813750	2.49	0.095
Number of Workers	2	3341932500	1670966250	174.86	0.000
S DELAY	2	363947500	181973750	19.04	0.000
Total	53	9928233750			

Table 6: 14 - Analysis of Variance for Electrical Actual Cost

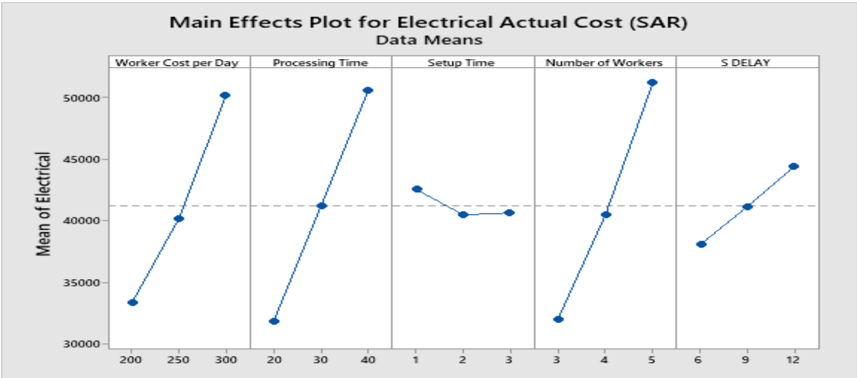

Figure 6: 8 - Main Effects Plot for Electrical Actual Cost (SAR)

6.4.9 Analysis of Drywall Actual Time

The ANOVA variance analysis for drywall actual time shows that processing time, setup time and suppliers' delay all have statistically significant impact on actual drywall time with P-values of 0.000. However, the actual drywall time appears to correlate more strongly with processing time and suppliers' delay than with set up time. In fact, its correlation with the setup time doesn't appear to be sharp enough (*See* Table 6:15 and Figure 6:9). The other two independent variables don't have a statistically significant impact on drywall time. The P-values for both 'worker cost per day' and 'number of workers' were found be higher than 0.05, with each recording a P-value of 0.377.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	0.593	0.296	1	0.376
Processing Time	2	300.593	150.296	507.25	0.000
Setup Time	2	28.593	14.296	48.25	0.000
Number of Workers	2	0.593	0.296	1	0.376
S DELAY	2	207.259	103.63	349.75	0.000
Total	53	550.37			

Table 6: 15 - Analysis of Variance for Drywall Actual Time

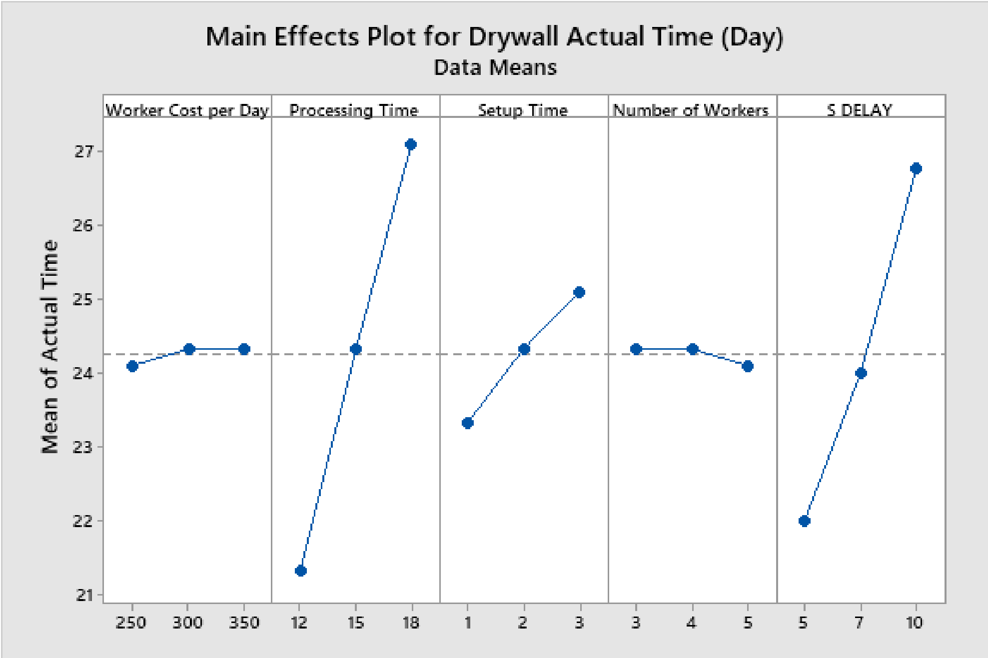

Figure 6: 9 - Main Effects Plot for Drywall Actual Time (Day)

6.4.10 Analysis of Drywall Actual Cost

The ANOVA analysis of variances for drywall actual cost shows that all of the independent variables have statistically significant relationship with drywall actual cost except for 'setup time' turned out to have a P-value of more than 0.05. The worker cost per day, processing time, number of workers and suppliers' delay were all found to have P-values of 0.000. Setup time has a P-value of 0.094. Interestingly, the actual drywall cost appears to correlate more strongly with number of workers and worker cost per day than with the other variables. In fact, its correlation with the suppliers' delay doesn't appear to be as sharp as in the other variables (*See* Table 6:16 and Figure 6:10). It is not clear why the 'setup time' variable turned out to have a statistically insignificant impact on drywall actual cost, but it could be because the activity of drywall installation doesn't require or rarely involve the use of heavy or specialist machineries whose setup times may be time-consuming and costly.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	796107315	398053657	209.37	0.000
Processing Time	2	409497315	204748657	107.7	0.000
Setup Time	2	9511481	4755741	2.5	0.094
Number of Workers	2	1738440648	869220324	457.21	0.000
S DELAY	2	272851481	136425741	71.76	0.000
Total	53	3308158009			

Table 6: 16 - Analysis of Variance for Drywall Actual Cost

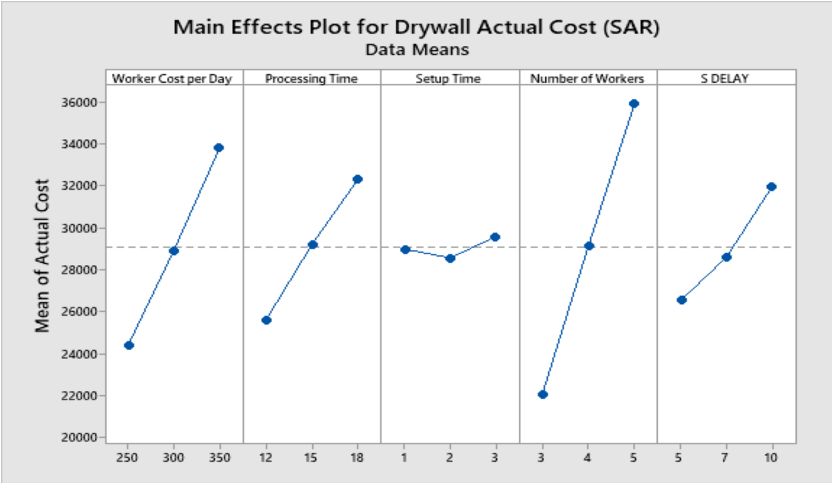

Figure 6: 10 - Main Effects Plot for Drywall Actual Cost (SAR)

6.4.11 Analysis of Exterior Casework Actual Time

The ANOVA variance analysis for exterior casework actual time shows that processing time, setup time and suppliers' delay all have statistically significant impact on actual exterior casework time with P-values of 0.000. However, the actual exterior casework time appears to correlate far more strongly with suppliers' delay than with the other variables. In fact, its correlation with the setup time doesn't appear to be sharp enough (*See* Table 6:17 and Figure 6:11). The remaining two independent variables don't appear to have a statistically significant impact on actual exterior casework time. The P-values for 'worker cost per day' and 'number of workers' were found be 0.929 and 0.535 respectively which are higher than the cutoff value of 0.05 for statistically significant correlations.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	0.7	0.352	0.07	0.9290
Processing Time	2	931.81	465.907	97.9	0.0000
Setup Time	2	232.26	117.13	24.4	0.0000
Number of Workers	2	7.04	3.019	0.63	0.5350
S DELAY	2	380.7	190.352	40	0.0000
Total	53	1757.15			

Table 6: 17 - Analysis of Variance for Exterior Casework Actual Time

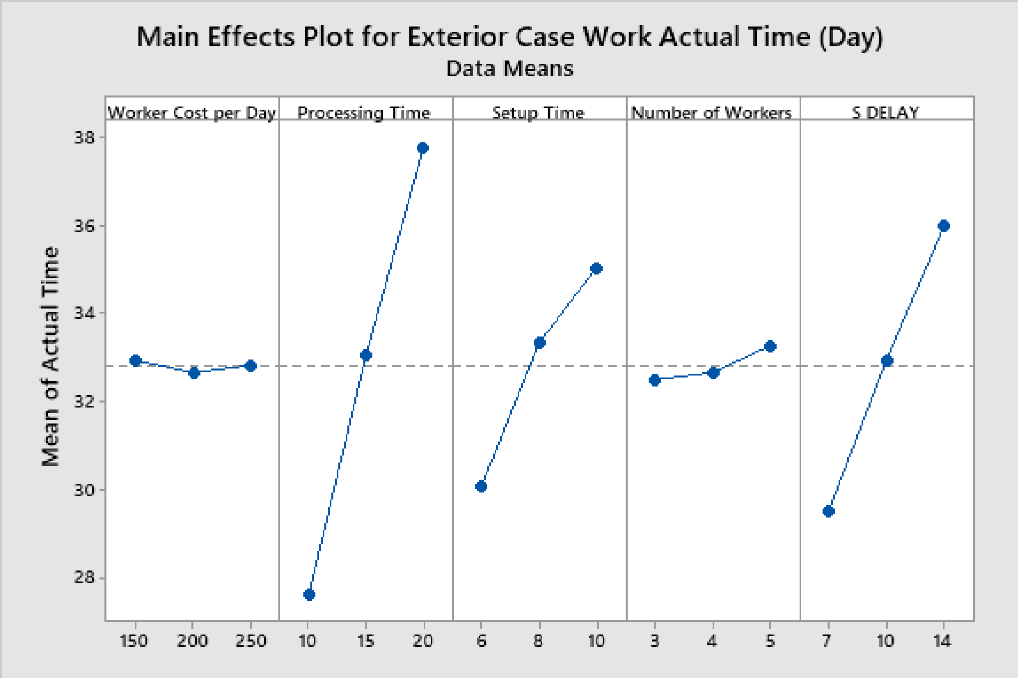

Figure 6: 11 - Main Effects Plot for Exterior Casework Actual Time (Day)

6.4.12 Analysis of Exterior Casework Actual Cost

The ANOVA variance analysis for exterior casework actual cost shows that the construct has statistically significant correlation with all of the independent variables. However, exterior casework actual cost seems to correlate more strongly with worker cost per day, processing time, number of workers than with setup time and suppliers' delay. The first set of variables has P-values of less than 0.000 whereas setup time and suppliers' delay have P-values of 0.002 and 0.001 respectively. Notably, the actual exterior casework cost appears to correlate more strongly with worker cost per day and number of workers than with all other variables. In fact, its correlation with setup time and the suppliers' delay doesn't appear to be as sharp as with the other variables (*See* Table 6:18 and Figure 6:12).

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Worker Cost per Day	2	1765135833	882567917	84.02	0.000
Processing Time	2	629950833	314975417	29.99	0.000
Setup Time	2	152525833	76262917	7.26	0.002
Number of Workers	2	1522435833	761217917	72.47	0.000
S DELAY	2	167735833	83867917	7.98	0.001
Total	53	4689443333			

Table 6: 18 - Analysis of Variance for Exterior Casework Actual Cost

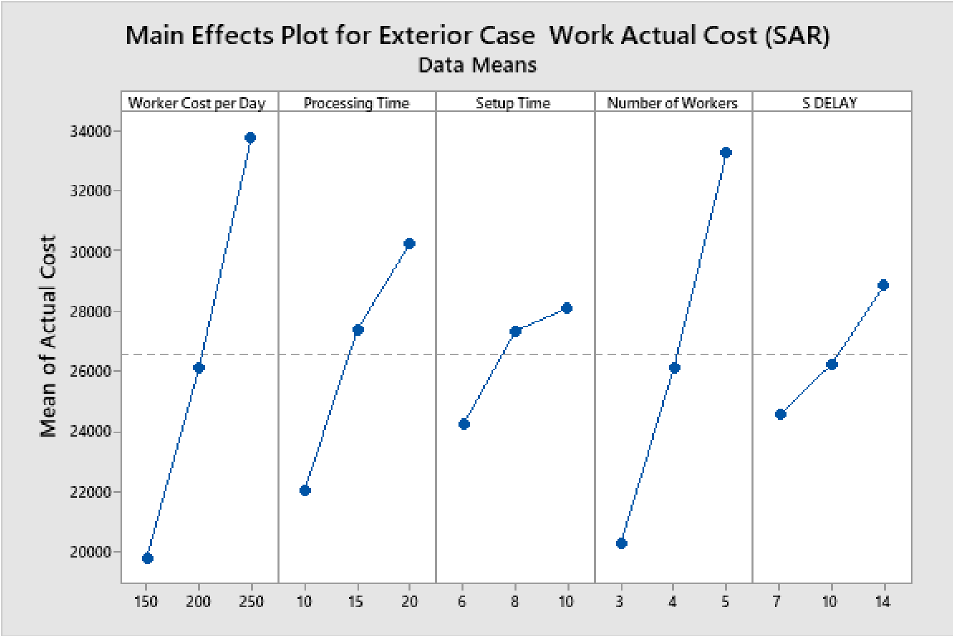

Figure 6: 12 - Main Effects Plot for Exterior Casework Actual Cost (SAR)

6.5 Summary

This chapter presented and discussed the outputs of the analysis of the current state of the operational performance of the Binladin Construction Company. It examined the nature of relationship between the cost and time of construction activities (i.e. framing, windows, electrical, elevators, drywall, and exterior casework) on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand. The author used the Minitab software to organise and analyse the relevant data. ANOVA analysis in particular had been used to explore the nature of relationships between six key construction activities and five performance indicators. The ANOVA analysis enabled the author to assess the statistical significance of the relationships between the two groups of variables. Tables 6:19 and 6:20 below summarise the nature of the identified correlations/relationships. The Tables show which variables have been found to have statistically significant (SS), very statistically significant (VSS) or highly statistically significant (HSS) impact on the time and cost of each construction activity. A value of 0 means that the variable has no impact on the activity's cost and time, whereas a value of 1 means that the variable has an impact on either the cost or time of the activity in question. Moreover, a value of 2 means that the independent variable has an impact on both, the cost and time of the activity in question. The Table 6:20 indicates that the 'processing time' variable has often had a HSS or VSS impact on almost all of the construction activities under study. In fact, it has been found to be the single most influential variable in terms of its impact on the cost and time efficiencies of construction activities. It is followed by the 'suppliers' delay' variable with a total impact value of 10.

Activity	Performance Indicator (Independent Variable)	HSS	VSS	SS
Framing	Worker Cost per Day	0	2	0
	Processing Time	2	0	0
	Setup Time	0	1	0
	Number of Workers	1	0	0
	Suppliers' Delay	0	1	0
Windows	Worker Cost per Day	0	1	0
	Processing Time	2	0	0
	Setup Time	0	0	2
	Number of Workers	1	0	0
	Suppliers' Delay	0	2	0
Elevators	Worker Cost per Day	1	0	0
	Processing Time	2	0	0
	Setup Time	0	0	2
	Number of Workers	1	0	0
	Suppliers' Delay	1	1	0
Electrical	Worker Cost per Day	0	1	0
	Processing Time	2	0	0
	Setup Time	0	0	1
	Number of Workers	0	1	0
	Suppliers' Delay	0	0	2
Drywall	Worker Cost per Day	0	1	0
	Processing Time	0	2	0
	Setup Time	0	0	1
	Number of Workers	0	1	0
	Suppliers' Delay	0	1	1
Exterior Casework	Worker Cost per Day	0	0	0
	Processing Time	0	1	0

	Setup Time	0	0	1
	Number of Workers	0	0	0
	Suppliers' Delay	0	0	1

Table 6: 19 - Nature of Identified Correlations

Activity	Performance Indicator (Independent Variable)	HSS	VSS	SS	Total
Totals	Worker Cost per Day	1	5	0	6
	Processing Time	8	3	0	11
	Setup Time	0	1	7	8
	Number of Workers	3	2	0	5
	Suppliers' Delay	1	5	4	10

Table 6: 20 - Totals of Identified Correlations

Chapter 7: Kanban-Facilitated Improvements

7.1 Introduction

This chapter demonstrates how the adoption of Kanban's rules could help the Binladin Construction Company / BCC to improve its operational efficiency in general and to reduce delays in particular. Kanban is one of Lean management tools. It is typically used by organisations to improve their operational performance by streamlining operations and balancing their operational capacity with 'real' demand. Although Kanban is predominantly used in the automotive industry, it has recently become popular in various other industries like construction, food, electronics, healthcare and even software development.

The results presented in this chapter are based on the data which was collected from the case-study firm and consequently on the design of experiment (DoE). They are also based on discrete event simulations (DES) of BCC's current state and Kanban-facilitated improved state. The simulation activities revolved around six key construction operations; namely, framing, windows, electrical, elevators, drywall and exterior casework. For each operation, 54 scenarios of 'supply delay' have been used to simulate how the use of Kanban's rules may affect the number of days lost to delays. In general terms, the simulation of the impact of Kanban's principles of 'supply delay' has shown significant improvements and notable reductions in the number of days lost to avoidable delays.

7.2 Kanban's Improvement Potential

There are numerous Lean construction tools and techniques which could help Saudi construction firms to improve their operational performance, but this research focused primarily on the applications, benefits and implications of Kanban. Leonardo et al. (2017) referred to Kanban as a pull production management tool which ensures that "a product is produced by a workstation according to its immediate downstream needs". He explained that Kanban helps to improve operational performance by making sure that "when certain parts are required at the end of a line, card(s) is/are passed to the beginning of the line to fulfil that need". There are also other applications of Kanban. For example, Kabadurmus and Durmusoglu, (2019) stated that Kanban is commonly "used to solve problems such as machine failure, defective parts and short-term demand rise".

There are many papers in the literature that discuss the efficiency-improving potential of Kanban especially in relation to reducing cost and time overruns. For instance, Forbes and Ahmed (2011), in their investigation of the implementation of Lean's tools and techniques by construction firms, found that Kanban's adoption could help boost productivity and quality by as much as 77%. Vieira and Cachadinha, (2011) explained that Kanban enables firms to boost productivity by reducing upstream variability, smoothening workflows and more importantly by improving coordination between different project teams. Moreover, Hannis-Ansah et al. (2016) reported that the employment of Kanban's rules enabled Danish firms to boost productivity by 20%, reduce project's lead-times by 10%, improve efficiency by 20% and increase projects' profitability by 20% - 40%. Jang and Kim (2007) also investigated the use of Kanban in production control and found that the implementation of Kanban's rules had helped to reduce safety accident in construction projects by 33%, to reduce costs by 5% and to improve scheduling performance by around 10% within 6 months of operationalisation. Also, More et al. (2016) investigated the adoption of pro-Lean techniques in the context of Indian construction firms and found that the operationalisation of Kanban's rules could improve the project's lead-times by as much as 31%, but explained that the rate of improvement could differ from one country to another. They, however, asserted that the use of Kanban's rules in conjunction with other Lean's tools and techniques would help construction firms to improve their operational efficiency by at least 25%.

The use of Kanban as an improvement strategy to address the problem of time and cost overruns in the Saudi construction industry has enabled the author to fill a significant gap in the literature. Alzara et al. (2016) reported that at least "70% of Saudi public projects" experienced delays due to contractors' failures to establish accurate timelines and also due to their inabilities to deploy their resources efficiently. This problem starts as early as the planning phase and continues throughout a project's lifecycle. Another study by Noman et al. (2018) investigated the causes of delays in Saudi construction projects and found that nearly all the projects experienced delays, and concluded that contractors' poor technical and material capabilities were the primary causes of delay for around 82% of the projects.

The author believes that the principles, practices and systems of Lean Construction in general and the six rules of Kanban in particular offer Saudi construction firms effective and viable solutions to the problem of time and cost overruns. Unfortunately, studies that investigate the adoption of LC in the Saudi construction industry are scarce or nonexistent. In an attempt to fill this gap, the author has set out to explore the applications, the potential benefits and implications of Lean's Kanban's adoption in the context of Saudi construction firms especially in terms of Kanban's impact on operational performance.

7.3 Improvement Strategy

This part of the chapter demonstrates how Kanban's principles have been linked to each of the construction activities under investigation. First, it is important to illustrate the steps that the author had to take in order to assess Binladin Construction Company's current state and to simulate the improvement potential of Kanban when used in conjunction with other Lean construction's tools, techniques and management systems. Figure 7:1 illustrates the processes the author followed in order to simulate Kanban's improvement potential using BCC's data. Second, it is important to note that the author performed discrete event simulation (DES) using SIMIO 10 software. The simulation process involved 54 scenarios of supply delay for each construction activity - 54 scenarios for current state and 54 scenarios for after the use of Kanban's rules. Kanban has six primary rules or principles; namely: (1) don't pass defective products in subsequent process; (2) procure only what's needed; (3) produce exact quantities of required products/parts; (4) level the production; (5) fine-tune production processes; and (6) stabilise and rationalise processes. Tables 7:1 - 7:6 demonstrate how each of Kanban's rules has been linked to the construction activities under study. The operational context of each activity had been taken into account when linked to Kanban's rules.

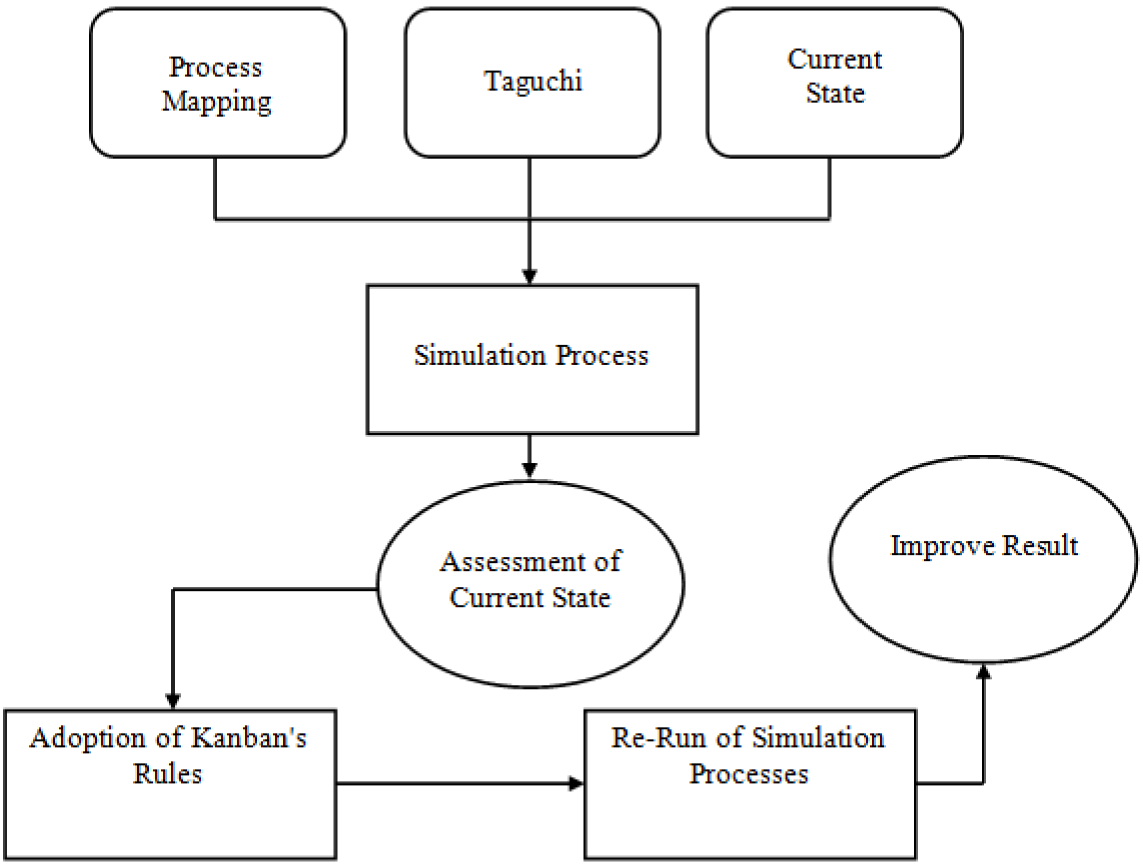

Figure 7: 1 - Steps of Improvement

7.3.1 Applying 6-Rules of Kanban to Framing

Table 7:1 illustrates how the employment of Kanban's rules could help the Binladin Construction Company / BCC to reduce delays and boost efficiency of framing processes and operations. It highlights the current state of performance and provides practical recommendations on what BCC needs to do in order to overcome its current problems and to achieve better results. Information about the 'current state' of the framing operations has been obtained using discussions with BCC's construction project manager, operations project manager, and assistant project manager.

Framing Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- It is not uncommon for defective components and parts of frames to be passed on from the upstream process and only identified at later stages. -There are instances when defective components/parts are knowingly passed on to downstream process with the hope that other teams will fix the defect before the use of the component.	- BCC needs to introduce a quality management policy to ensure that defective parts or components are never passed onto downstream processes. - BCC also needs a signalling system that sounds the alarm whenever defective parts or poor quality parts are received from upstream processes.
(2) Procure only what's needed	- It is a normal practice at BCC for the downstream teams to over-order parts or components as precaution to avoid shortages. - Project managers have so little regard to the extra costs incurred due to overproduction and storage of additional inventory.	- BCC needs to introduce new operational policies that will require downstream processes to only pull what they need in order to avoid overproduction, reduce costs, and make the construction operations more reflective of the progress.
(3) Produce exact quantities required	- Although most of BCC's suppliers have what's known as 'manufacture-to-order' policies, a few of its suppliers overproduce as a strategy to avoid shortages. Overproduction results in backlogs and hinders their abilities to respond to new, more urgent requests. Also,	- BCC needs to work closely and collaboratively with its suppliers to address the issue of over-production as means of reducing cost, saving time and avoiding backlogs. - BCC should streamline its in-house production activities with its exact needs so that framing components / parts

	over-supply of framing components increases the risk of having the parts deteriorate or even become obsolete.	are only manufactured when needed and in quantities that precisely match its needs.
(4) Level the production	- The activities which are directly linked to framing are poorly levelled. The preceding processes over-produce, whereas the downstream processes are not moving fast enough. This more often than not causes bottlenecks and restricts BCC's ability to optimise the efficiency of the framing operation.	- BCC should first measure and monitor the capacity of each and every activity or process that's directly related to framing, downstream and upstream. This should help the firm to identify the causes of any bottlenecks. - BCC should ensure that the capacities of upstream and downstream processes are perfectly aligned. - BCC should address current bottlenecks in the framing operation through effective Augmentation of resources and by setting a realistic and practical work-in-progress limit based on the relevant limiting contributors.
(5) Fine-tune processes	- Although BCC has tried, for many years to achieve optimal efficiency, its operations are far from being finely-tuned. The construction activities are not well coordinated and don't flow as well as they should. Also, it is quite common for framing processes to be held up due to bottlenecks. This is evident in longer than expected lead time and cycle times. The process's throughput is also not as high as it should.	- BCC should use Kanban's tools and metrics to identify and deal with choke points and bottlenecks. Upstream and downstream processes can be more finely-tuned through elimination of all forms of waste such as defects, rework, waiting time and unnecessary handoffs. This will require the firm to use cross-functional team to identify problems and come up with good solutions.
(6) Stabilise and rationalise processes	- BCC has a wide range of policies in place that help to stabilise processes, but they need some changes. The framing activity currently lacks the desired level of standardisation.	- BCC needs to have explicit and rigorous standards for the framing activity to provide the right levels of predictability and consistency which are crucial for the achievement of optimal operational efficiency.

	There aren't clear and rigorous standards against which workers' as well as contractors' performances can be measured. This hinders the firm's ability to stabilise the processes and activities of framing.	-BCC should have a cross-functional team who is given the responsibility for the development and review of process standards. It is vital that standards are continually reviewed and updated so that they remain consistent with industrial best practices.
Recommendations: The adoption and operationalisation of Kanban's rules would almost certainly help BCC to reduce delays and optimise the efficiency of its framing operations. First, BCC should have a strong quality management policy which strictly ensures that defective parts or components are never passed onto downstream processes. Second, BCC's downstream processes must only pull what they need from upstream operations to avoid overproduction and to reduce costs. Third, BCC should make sure that framing components are only manufactured when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to reduce bottlenecks and avoid backlogs. Fifth, BCC should fine-tune its upstream and downstream processes through the continuous identification and elimination of operational waste such as unnecessary processing. Sixth, BCC should embark on a journey of systematic standardisation of framing processes to ensure good levels of stability, consistency, predictability and most importantly high quality.		

Table 7: 1 - Improving Framing Construction through Employment of Kanban's Rules

7.3.2 Applying 6-Rules of Kanban to Windows

Table 7:2 highlights the current efficiency issues with the construction of windows by the Binladin Construction Company / BCC and shows how the employment of Kanban's rules could help the firm to reduce delays and boost the efficiency of windows' construction's processes and operations. It highlights the current state of performance and provides suggestions on what BCC needs to do in order to overcome its current problems. Information about the 'current state' of the windows operations has been obtained using discussions with BCC's construction project manager, operations project manager, and assistant project manager.

Windows Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- Like in the case of the framing activity, there are times when defective parts or components of windows are passed on from the upstream process and only identified at later stages. - Defective components are often only noticed by the installation teams who then put their activities on hold	- BCC needs to introduce a quality management policy to ensure that defective parts or components are never passed onto downstream processes. - BCC also needs a signalling to raise the alarm when a defective component or poor quality parts are received from upstream teams / processes.

	until the defective parts are fixed or replaced.	
(2) Procure only what's needed	- It is common for the downstream teams at BCC to over-order parts or components as precaution to avoid shortages. - Project managers have so little regard to the extra costs incurred due to overproduction and storage of additional inventory.	- BCC needs to introduce new operational policies that will require downstream processes to only pull what they need in order to avoid overproduction, reduce costs, and make the procurement operations more streamlined with needs.
(3) Produce exact quantities required	- It is common for BCC's suppliers to use a make-to-order production policy, but still a few of its suppliers overproduce as a strategy to avoid shortages. Overproduction results in backlogs and hinders their abilities to respond to new, more urgent requests. Also, over-supply of windows parts increases the risk of having the parts deteriorate or even become obsolete.	- There is a need for BCC to work closely with its suppliers to address the issue of over-production as means of saving time and avoiding backlogs. -BCC also needs to have more streamlined in-house production activities so that windows components are only manufactured when needed and in exact quantities.
(4) Level the production	- The activities related to windows construction are not very complicated, but there is a misalignment between the capacities of different processes - the preceding processes over-produce, whereas the downstream processes are not moving fast enough. This usually leads to bottlenecks and hinders BCC's efforts to achieve optimal performance.	- The capacity of each and every activity or process that's directly related to windows, downstream and upstream should be measured. This will help BCC to identify the root causes of bottlenecks. - The capacities of upstream and downstream processes need to be more closely aligned with each other. - The current bottlenecks in the windows activity should be addressed by augmenting resources and setting realistic and work-in-progress limits.
(5) Fine-tune processes	- BCC's windows activity might appear efficient on face value, but it far from being finely-tuned. The windows-related activities aren't well coordinated and	- BCC should identify and address the choke points and bottlenecks using Kanban's tools and techniques. Also the upstream and downstream processes needs to be better

	don't flow as well as they should. There is also the problem of bottlenecks. This is evident in longer than expected lead time and the throughput is also not as high as it should.	tuned. This could be achieved through elimination of useless and wasteful activities such as rework, and waiting time. - BCC should also use cross-functional teams to identify problems and bottlenecks and to provide viable solutions.
(6) Stabilise and rationalise processes	- Although BCC has well-rationalised processes, not enough is being done to ensure stability and to guarantee consistency. In its current state, the windows activity lacks the right standardisation level. There aren't explicit and rigorous standards against which workers' as well as contractors' performances can be measured. This hinders the firm's ability to stabilise the activity of windows construction.	- There needs to be a set of explicit and rigorous standards for the windows activity to facilitate greater degrees of predictability and consistency which are crucial for optimal operational efficiency. - There is a need for greater use of cross-functional teams to facilitate the development rigorous process standards. It is vital that standards are continually updated so that they remain consistent with industrial best practices.
Recommendations: Again, the adoption and operationalisation of Kanban's rules would help BCC to reduce delays and problems of its windows operations. First, BCC should have a rigorous quality management policy that strictly ensures that defective parts are never passed onto downstream processes. Second, BCC's downstream processes must only procure what they need from upstream operations. Third, BCC should make sure that windows parts are only manufactured when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to avoid bottlenecks. Fifth, BCC needs to fine-tune its upstream and downstream processes through the identification and elimination of wasteful activities. Sixth, BCC should begin systematic standardisation of windows processes to ensure good levels of stability, consistency, predictability and quality.		

Table 7: 2 - Improving Windows Construction through Employment of Kanban's Rules

7.3.3 Applying 6-Rules of Kanban to Electrical

Table 7:3 highlights the current problems with the electrical activity of Binladin Construction Company especially in terms of efficiency. It also demonstrates the extent to which Kanban's 6 rules of management could help the firm to address some of its inefficiencies and optimise the performance of its electrical installation processes and operations. Information about the 'current state' of the electrical operations has been obtained using discussions with BCC's construction project manager, operations project manager, and assistant project manager.

Electrical Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- BCC's teams rarely pass on defective electrical parts or components downstream and supplies are often sourced from reputable suppliers with high quality. -There have been instances when electrical work has had to be put on hold due to the fact that suppliers don't precisely match the required standards and/or the ordered specifications.	- These minor quality issues can easily be addressed by introducing a good quality inspection policy to ensure that defective parts or components are never passed on to downstream processes and also to ensure that the ordered supplies perfectly match the required standards and electrical specifications.
(2) Procure only what's needed	- As is the case in other construction activities, it is a normal practice at BCC for the downstream teams to over-order parts or supplies as precaution to avoid shortages. This tactic is only effective if the over-ordered supplies match the standards and specifications required. - It seems that BCC's project managers have little regard to the extra costs incurred as a result of holding additional and sometimes unnecessary inventory.	- In order to reduce cost and improve efficiency, BCC's teams need to stop the current practice of over-procurement and should only procure what they need at the right time.
(3) Produce exact quantities required	- BCC doesn't produce electrical supplies, so this rule doesn't necessarily apply to this particular activity. However, the firm could work with its suppliers to reduce the cost of supplies and mitigate the risk of delays in deliveries.	- BCC should consider the idea of working closely and collaboratively with its suppliers to address the issue of over-production as means of reducing cost, saving time and avoiding backlogs. - BCC should also streamline its procurement operations so that electrical supplies are only order when needed and in quantities that precisely match its needs.
(4) Level the production	- Again, BCC does not produce electrical supplies,	- In order to level the activity of electrical installations with

	so the rule of 'level the production' does not necessarily apply to this particular activity. It may, however, apply principally to the installation processes of electrical systems. For example, there's currently a mismatch between the speed by which electrical systems are installed and other downstream activities such as the installations of lightings, elevators and HVAC. This issue causes unnecessary waiting times and bottlenecks. It could, however, be avoided by levelling downstream and upstream activities.	downstream and upstream activities, BCC would need to first measure and monitor the capacity of the activities that come before and after the electrical operation. This is vital to identifying the root causes of any bottlenecks. Then, BCC would need to ensure that the capacities of upstream and downstream processes are perfectly aligned either through augmentation of resources or by setting a realistic and practical work-in-progress limits.
(5) Fine-tune processes	- BCC is putting a lot of effort into improving the efficiency and flow of its processes. However, it isn't accurate to claim that the firm's electrical activity is finely-tuned when one pays attention to how connect with each other. Processes don't flow as well as they should and there is a lack of alignment between the downstream and upstream operations. Activities aren't streamlined well and that is causing unnecessarily long lead time and suboptimal speed and productivity.	- Kanban's primary purpose is help firms to finely tune their processes and operations by overcoming flow problems (i.e. bottlenecks and backlogs) and through elimination of operational waste when used in conjunction with other Lean tools and techniques. Thus, BCC should employ Kanban's tools to identify the root cause bottlenecks and find practical solutions to flow problems by using cross-functional teams.
(6) Stabilise and rationalise processes	- Kanban's 6th rule requires firms to stabilise processes through standardisation of processes and procedures. Unfortunately, the activity of electrical installation at BCC lacks standardisation. Specialists do not always follow strict processes and procedures when putting systems in place. Instead, they rely on their expertise and follow their instincts in making sure that electrical	- Evidently, in order for BCC to rationalise and stabilise its electrical operations, it needs to have rigorous standards for the electric activity to provide the right levels of consistency and quality which are crucial for the achievement of optimal operational efficiency. - BCC's electric installations' standards must be continually reviewed and updated by the right cross-functional teams to

	systems are installed in a way that complies with the manufacturer's standards. This behaviour undermines the firm's ability to sustain its quality standards.	sustain their consistency with industrial best practices.
Recommendations: The efficiency of BCC's electrical operations could be improved significantly through the adoption and operationalisation of Kanban's rules. First, BCC needs to have a good quality management policy that strictly ensures high quality standards of electric supplies. Second, BCC's downstream processes must only procure what they need to avoid unnecessary storage costs. Third, BCC should make sure that electric supplies are only ordered when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to reduce bottlenecks and avoid backlogs. Fifth, BCC should fine-tune its upstream and downstream processes through the continuous identification and elimination of operational waste such as waiting time. Sixth, BCC should systematically standardise its electric processes to ensure good levels of stability and quality.		

Table 7: 3 - Improving Electrical Activities through Employment of Kanban's Rules

7.3.4 Applying 6-Rules of Kanban to Elevators

Table 7:4 highlights the current state of elevators construction operations at the Binladin Construction Company and demonstrates the consistency of Kanban's rules with the firm's operational needs and circumstances. It also highlights how Kanban's rules can be used by BCC to reduce delays and to improve the efficiency of elevator construction processes and procedures. It provides practical recommendations on what BCC needs to do in order to overcome its current problems and to boost its operational performance. Information about the 'current state' of the elevators operations has been obtained using discussions with BCC's construction project manager, operations manager, and assistant project manager.

Elevators Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- Construction of elevators involves both external and in-house production of the required parts, components, systems and installations. Consequently, it isn't at all uncommon for defective parts or essential supplies to be passed on the team responsible for elevators from upstream operations. When this occurs, it results	- BCC needs to have rigorous quality inspection policies to ensure that defective parts or components don't ever pass on to downstream processes. The firm also needs a good quality compliance policy to ensure that all supplies are of highest quality standards. - BCC also needs a signalling system that raises the alarm

	in unnecessary delays and additional processing costs especially when operations are put on hold which has a knock-on effect on the timelines and efficiency of downstream operations. It isn't at all common for the supplies of elevators to fail quality standards or fail to meet the specifications, but it's more common for the in-house produced parts to have defects that require fixing or rework.	whenever defective parts or poor quality parts are received from upstream processes.
(2) Procure only what's needed	- It is a normal practice for downstream teams to over-order parts or supplies due to fear of shortages. This strategy is only effective if the supplies match the right standards and the required specifications. It is also a sign of inefficiency for the firm to over-procure for its in-house production. - Unfortunately, the firm's project managers have little worry about the additional costs incurred as a result of holding unnecessary stock.	- BCC's teams responsible for the construction of elevators should only procure what they need only when they need it in order to reduce cost and boost efficiency. They should stop the current inefficient practice of over-procurement.
(3) Produce exact quantities required	- Many of BCC's suppliers don't have Lean systems in place, so it's common for them to over-produce even through the practice leads to additional costs. These additional costs are then transferred onto buyers like BCC in the form of higher supplies' prices. - The in-house production activities of BCC also have an overproduction problem which has, for very long, hindered the firm's efforts to optimise its operations.	- With the help of Kanban, BCC will be able to streamline its production and installation operations so that parts are only produced or procured when needed and in quantities that precisely match its needs. -BCC must also work closely with its primary suppliers to deal with the problem of over-production in order to reduce cost, lead-times and backlogs.
(4) Level the production	- Evidently, some of BCC's activities which are directly related to the construction	- BCC should use Kanban to help it ensure that the capacity of every process that's directly

	of elevators are poorly levelled. Some of processes over-produce, whereas the downstream processes are moving slowly. This often causes bottlenecks which undermine BCC's ability to optimise the efficiency of the elevators' installations. - There are parts of the elevators which BCC does not produce internally, so this rule only applies to the firm partially. For example, there's a mismatch between the speed of installation of elevators and downstream activities like the lightings and HVAC installations. This causes waiting times which can be avoided by levelling downstream and upstream activities.	related to elevator installation downstream and upstream are aligned well with each other. To achieve this, BCC would first need to measure the capacity of the activities that come before and after the elevators activity. This is vital to identifying the root causes of any bottlenecks. Only then can BCC facilitate alignment through resource augmentation and by setting realistic work-in-progress limits.
(5) Fine-tune processes	- Despite BCC's efforts to improve the efficiency and flow of its operations, the firm's elevator construction activity can't be said to be 'finely-tuned' as the related activities don't appear to be well-coordinated. There is misalignment between the downstream and upstream operations. Activities aren't streamlined well and that is causing unnecessarily long lead times and suboptimal speed and productivity.	- The adoption and application of Kanban's rules will surely help BCC to finely tune the elevator-related processes and by overcoming flow problems (i.e. bottlenecks and backlogs) and through ridding its value chain of wasteful activities. So, BCC should use Kanban's tools to identify the root cause bottlenecks and find practical solutions to flow problems by using cross-functional teams.
(6) Stabilise and rationalise processes	- Evidently, the elevators' construction processes are neither stable nor rational - the activity lacks the right degree of standardisation. It is also common for the specialists to not follow strict procedures during the installation process and instead follow their work instincts in making sure that systems are installed in	- For BCC to rationalise and stabilise its elevator-related operations, it needs to have rigorous standards for the activity that provide the right levels of consistency, quality and predictability which are crucial for the achievement of optimal operational efficiency.

	ways that comply with the standards of manufacturers.	
Recommendations: The efficiency of BCC's elevators operations could be improved significantly through the adoption and operationalisation of Kanban's rules. First, BCC needs to have a good quality management policy that strictly ensures high quality standards of elevators' supplies. Second, BCC's downstream processes must only procure what they need to avoid unnecessary storage costs. Third, BCC should make sure that supplies for the elevators are only ordered when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to reduce bottlenecks and avoid backlogs. Fifth, BCC should fine-tune its upstream and downstream processes through continuous elimination of operational waste. Sixth, BCC should systematically standardise its elevator processes to ensure good levels of stability and quality.		

Table 7: 4 - Improving Elevators Activities through Employment of Kanban's Rules

7.3.5 Applying 6-Rules of Kanban to Drywall

Table 7:5 demonstrates how the employment of Kanban's rules could help the Binladin Construction Company to reduce delays and improve drywall construction processes and procedures. It highlights the firm's current operational challenges and provides practical recommendations on what BCC needs to do in order to overcome its current problems and to achieve better performance. Information about the 'current state' of the drywall operations has been obtained using discussions with BCC's construction project manager, operations project manager, and assistant project manager.

Drywall Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- It is not uncommon for defective drywall parts to be passed on to the drywall construction team from the upstream process and only identified at later stages. -There are instances when defective components/parts are knowingly passed on to downstream process with the hope that other teams will fix the defect before the use of the component.	- BCC needs to have a quality management policy to ensure that defective components are never passed onto downstream processes and teams. - BCC also needs a signalling system that sounds the alarm whenever defective parts or poor quality parts are received from upstream processes.
(2) Procure only what's needed	- It is a normal practice at BCC for the downstream teams to over-order parts or	- BCC needs to introduce new operational policies that will require downstream processes to only pull what they need in

	components to mitigate the risk of shortages. - Project managers seem to have little regard to the extra costs incurred due to overproduction and storage of additional inventory.	order to avoid overproduction, and reduce costs.
(3) Produce exact quantities required	- Not all of BCC's suppliers have 'manufacture-to-order' policies, so it's common for some of the suppliers to overproduce to avoid the shortages. Overproduction, however, often leads to backlogs and hinders their abilities to respond to new, more urgent requests. Also, over-supply of drywall components increases the risk the parts deteriorate or even become obsolete.	- BCC needs to work closely with its suppliers to address the issue of over-production in order to reduce cost, save time and avoid backlogs. - BCC should streamline its in-house production activities with its exact needs so that drywall components / parts are only produced when needed and in quantities that precisely match its needs.
(4) Level the production	- The activities which are directly linked to drywall construction aren't levelled well enough. The upstream processes over-produce and the downstream processes aren't moving fast enough. This has usually caused bottlenecks and restricted BCC's efforts to optimise the efficiency of operations	- BCC Needs to make sure that the capacities of upstream and downstream processes are perfectly aligned. It should first measure the capacity of all relevant activities that are related to drywall construction and identify the causes of any bottlenecks. It should then re-allocate resources and set fine work-in-progress limits that perfectly match the capacities of co-dependent processes.
(5) Fine-tune processes	- At the moment, BCC's construction activities are not well coordinated and don't flow as smoothly as they should. Also, it's quite common for the drywall construction activities to be held up due to bottlenecks. This is evident by the long lead times and cycle times.	- BCC should use Kanban's tools to identify and deal with choke points and bottlenecks. Its processes may be better tuned through elimination of operational inefficiencies such as rework, and waiting time. This will require the firm to use Kaizen teams to identify problems and produce good and viable solutions.
	- BCC has a wide range of policies which provide a degree of stability, but they need some improvements.	- In line with Kanban's rules, BCC should have clear and rigorous standards for the drywall installation activity to

(6) Stabilise and rationalise processes	BCC's drywall construction activity currently lacks the right standardisation level. There aren't clear standards to which workers as well as contractors have to adhere. This hinders BCC's ability to stabilise and rationalise the drywall activities.	provide the right consistency and quality levels which are crucial for the achievement of optimal operational efficiency. -BCC should also use multi-skilled, cross-functional teams for development of process standards. The standards need to be continually reviewed and updated to keep up with the industrial best practices.
Recommendations: The adoption and operationalisation of Kanban's rules should help BCC to reduce delays and optimise the efficiency of its drywall operations. First, BCC should have a strong quality management policy which strictly ensures that defective parts or components are never passed onto downstream processes. Second, BCC's downstream processes must only pull what they need from upstream operations. Third, BCC should make sure that drywall components are only manufactured when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to reduce bottlenecks. Fifth, BCC should fine-tune its processes through the continuous identification and elimination of operational waste such as unnecessary processing. Sixth, BCC should undertake systematic standardisation of drywall processes to ensure the right levels of stability, consistency and quality.		

Table 7: 5 - Improving Drywall Construction through Employment of Kanban's Rules

7.3.6 Applying 6-Rules of Kanban to Exterior Casework

Table 7:6 highlights the current inefficiencies within exterior casework - related activities in the Binladin Construction Company and demonstrates how the employment of Kanban's rules could help the firm to reduce delays and boost the efficiency of exterior casework's processes and procedures. It also provides suggestions on what BCC needs to do in order to overcome its current problems. Information about the 'current state' of the exterior casework operations has been obtained using discussions with BCC's construction project manager, operations project manager, and assistant project manager.

Exterior Casework Activity		
Kanban's Rule	**Current State**	**Recommended Changes**
(1) Don't pass defective products	- Like in other construction activities, there are times when defective exterior casework parts are passed on from upstream process and get identified far down the production stream. - Defective components are often only noticed by the	- BCC needs to introduce a quality management policy to ensure that defective parts are never passed onto downstream processes. - BCC also needs a signalling system in place to sound the alarm when a defective / poor

	installation teams who then put their activities on hold until the defective parts are fixed or replaced.	quality parts are received from upstream teams / processes.
(2) Procure only what's needed	- It's quite typical of downstream teams to over-order parts or as precaution to avoid shortages. - Project managers also have so little regard to the extra costs incurred due to overproduction and storage of additional inventory.	- BCC needs to introduce new operational policies that will require downstream processes to only pull what they need in order to avoid overproduction, reduce costs, and make the procurement operations more streamlined with needs.
(3) Produce exact quantities required	- It is common for BCC's suppliers to use a make-to-order production policy, but some of its suppliers still overproduce out of fear of shortages. Generally overproduction often leads to backlogs and hinders the suppliers' ability to respond to more urgent requests. In addition, over-supply of parts increases the risk of having the parts deteriorate or even become obsolete.	- There is a need for BCC to work closely with its suppliers to address the issue of over-production as means of saving time and avoiding backlogs. -BCC also needs to streamline in-house production activities so that exterior casework parts are only produced when needed and in exact quantities.
(4) Level the production	- There are misalignments between the capacities of different processes at BCC - the processes preceding exterior casework activity occur at a faster rate than the downstream processes and that often leads to bottlenecks and hinders the firm's efforts to achieve optimal performance.	- The capacity of each and every activity or process that's directly related to exterior casework should be measured. This will help BCC to identify the root causes of bottlenecks. This will help the firm to align the capacities of upstream and downstream processes more closely. - The current bottlenecks in the may be overcome through augmentation of resources and by setting realistic and viable work-in-progress limits.
(5) Fine-tune processes	- BCC's exterior casework activity is efficient to some degree, but it's so far from being finely-tuned. Its associated activities aren't well coordinated and don't	- BCC should identify and address the choke points and bottlenecks using Kanban's tools and techniques. Also the upstream and downstream processes should be better

	flow as well as they should. There is also the problem of bottlenecks - the lead times are longer than they should and productivity is not as good as it should.	tuned. This could be achieved through elimination of useless and wasteful activities such as rework, and waiting time. - BCC should also use cross-functional teams to identify problems and bottlenecks and to provide viable solutions.
(6) Stabilise and rationalise processes	- Although BCC has well-rationalised processes, not enough is being done to maintain stability. In the current state, the exterior casework activity lacks standardisation. There are not rigorous standards that workers and contractors can use as a performance benchmark. This hinders the firm's ability to stabilise the construction processes of the exterior casework.	- There needs to be a set of explicit and rigorous standards for the exterior casework activity to facilitate greater degrees of predictability and consistency which are crucial for optimal efficiency. - There is a need for greater use of cross-functional teams to facilitate the development rigorous process standards. It is also vital that standards are continually updated.
Recommendations: The adoption of Kanban's rules would help BCC to reduce delays and boost efficiency. First, BCC should have a rigorous quality management policy. Second, BCC's downstream processes must only procure what they need. Third, BCC should make sure that parts are only manufactured when needed and in the right quantities. Fourth, BCC should align the capacities of upstream and downstream processes to avoid bottlenecks. Fifth, BCC needs to fine-tune its upstream and downstream processes. Sixth, BCC should begin systematic standardisation of exterior casework processes.		

Table 7: 6 - Improving Exterior Casework Construction through Employment of Kanban's Rules

7.4 Impact of Kanban's 6 Rules on Supply Delay

The adoption of Kanban's rules has been found to reduce supply delays notably in all of the six construction activities under investigation (i.e. framing, windows, electrical, elevators, drywall and exterior casework). SIMIO 10 has been used to simulate supply delay before and after the adoption of Kanban's rules using 54 real scenarios (*See* Figures 7:9 - 7:20). The simulation process involved several steps which were repeated for each of the 54 scenarios; and for every activity of the six construction activities under study. Firstly, a process map for the entire construction operation was constructed in the Simio simulation software (*See* Appendix VI, Figure 1). Secondly, the simulation variables for each scenario were inputted into the simulation model and then the simulation was run as shown in Appendix VI, Figure 2. Thirdly, the results were reviewed and transferred into an Excel spreadsheet for further analysis and interpretation. For example, in the first scenario of the 'framing' activity, the Simio model estimated that, before the adoption of Kanban, the total cost would be around 16,800 Saudi Riyals and the lead-time would be 28 days (*See* Appendix VI, Figure 3). The software also estimated that the framing activity would likely experience a delay of around 7 days (*See* Appendix VI, Figure 4). However, with Kanban, the software estimated that the total cost would drop to around 15,750 Saudi Riyals and the lead-time to be around 26.25 days (*See* Appendix VI, Figure 5). More importantly, the delay was estimated to fall by 6.25% to 5.25 days as shown in Appendix VI, Figure 6. This confirmed Kanban's potential to improve the cost and time efficiencies of the construction activity in question in this particular scenario.

Fourthly, once the relevant output data for each of the framing activity's 54 scenarios was transferred into Excel, the estimates were reviewed and organised in a way that facilitated further analysis. For example, tables and line charts had been used to illustrate the extent to which Kanban would help the Binladin Construction Company to reduce supply delays in all of the six construction activities under investigation. In the case of framing, the suppliers' delay used to range between 7 days and 15 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the framing activity will fall to below 11 days and can get as low as 5 days (*Refer* to Figure 7:10). Moreover, it usually takes the company between 28 days and 58 days to complete all of the framing-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 54 days and can get as low as 26 days (*Refer* to Table 7:7). The simulation results also show that Kanban's adoption can help the case-study company to reduce the lead time for the framing activity by as much as 10.14%. The scenarios show that the lead time can be as high as 58 days and as low as 26.25 days (*See* Figure 7:9 and Table 7:7).

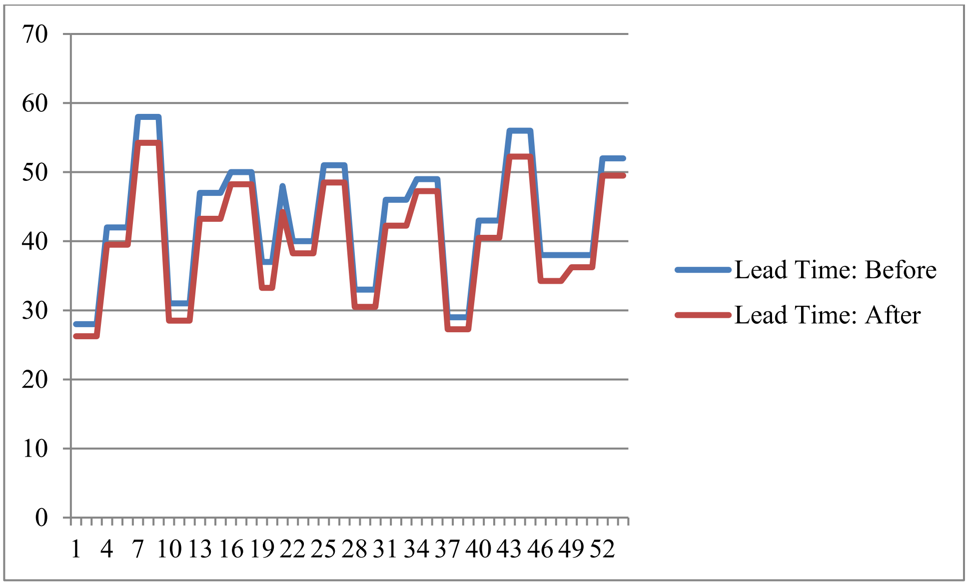

Figure 7: 2 Framing Lead Time for Before and After Kanban's Adoption

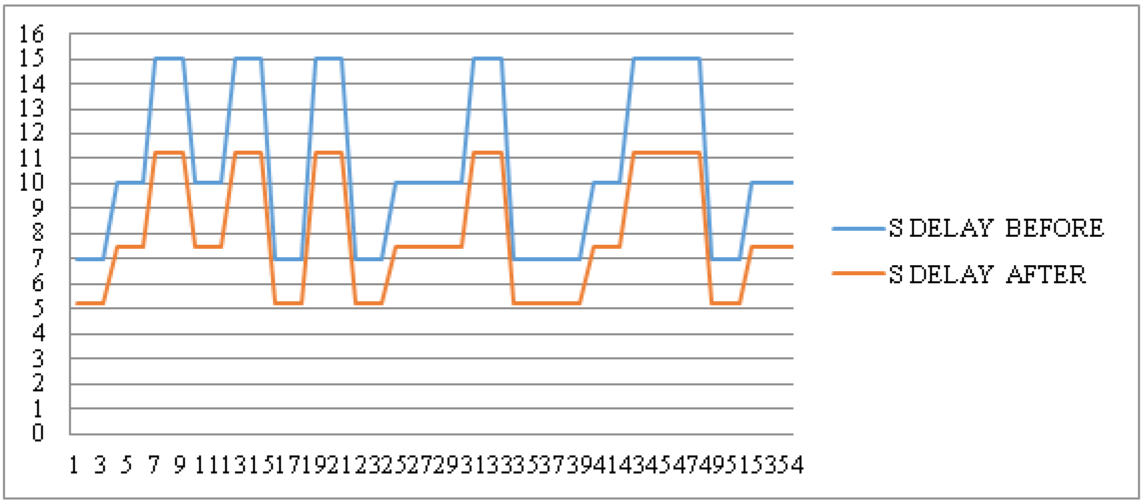

Figure 7: 3 - Kanban's Impact on Supply Delay in the Context of Framing Activity

Framing Activity			
	BEFORE	**AFTER**	
Number of Experiments	**Actual Time (Days)**	**Actual Time (Days)**	**Percentage of Improvement**
1	28	26.25	6.25%
2	28	26.25	6.25%
3	28	26.25	6.25%
4	42	39.5	5.95%
5	42	39.5	5.95%
6	42	39.5	5.95%

7	58	54.25	6.47%
8	58	54.25	6.47%
9	58	54.25	6.47%
10	31	28.5	8.06%
11	31	28.5	8.06%
12	31	28.5	8.06%
13	47	43.25	7.98%
14	47	43.25	7.98%
15	47	43.25	7.98%
16	50	48.25	3.50%
17	50	48.25	3.50%
18	50	48.25	3.50%
19	37	33.25	10.14%
20	37	33.25	10.14%
21	48	44.25	7.81%
22	40	38.25	4.38%
23	40	38.25	4.38%
24	40	38.25	4.38%
25	51	48.5	4.90%
26	51	48.5	4.90%
27	51	48.5	4.90%
28	33	30.5	7.58%
29	33	30.5	7.58%
30	33	30.5	7.58%
31	46	42.25	8.15%
32	46	42.25	8.15%
33	46	42.25	8.15%
34	49	47.25	3.57%
35	49	47.25	3.57%
36	49	47.25	3.57%
37	29	27.25	6.03%

38	29	27.25	6.03%
39	29	27.25	6.03%
40	43	40.5	5.81%
41	43	40.5	5.81%
42	43	40.5	5.81%
43	56	52.25	6.70%
44	56	52.25	6.70%
45	56	52.25	6.70%
46	38	34.25	9.87%
47	38	34.25	9.87%
48	38	34.25	9.87%
49	38	36.25	4.61%
50	38	36.25	4.61%
51	38	36.25	4.61%
52	52	49.5	4.81%
53	52	49.5	4.81%
54	52	49.5	4.81%

Table 7: 7 - Actual Time Improvements of Framing Activity

In the case of windows activity, the suppliers' delay used to range between 5 days and 15 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the windows activity will fall to below 11 days and can get as low as 4 days (*See* Figure 7:12). Moreover, it usually takes Binladin Construction Company / BCC between 26 days and 58 days to complete all of the windows-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 54 days and can get as low as 25 days (*Refer* to Appendix VII – Table 1). The simulation results also show that Kanban's adoption can help the case-study company to reduce the lead time for the windows activity by as much as 10%. The scenarios show that the lead time can be as high as 58 days and as low as 24.75 days (*Refer to* Figure 7:13 and Appendix VII – Table 1).

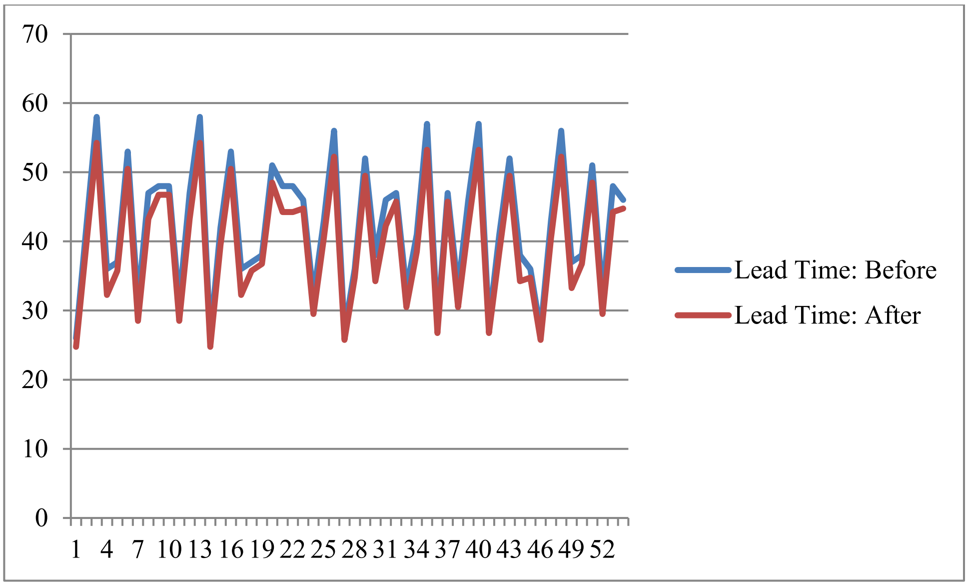

Figure 7: 4 Windows Lead Time for Before and After Kanban's Adoption

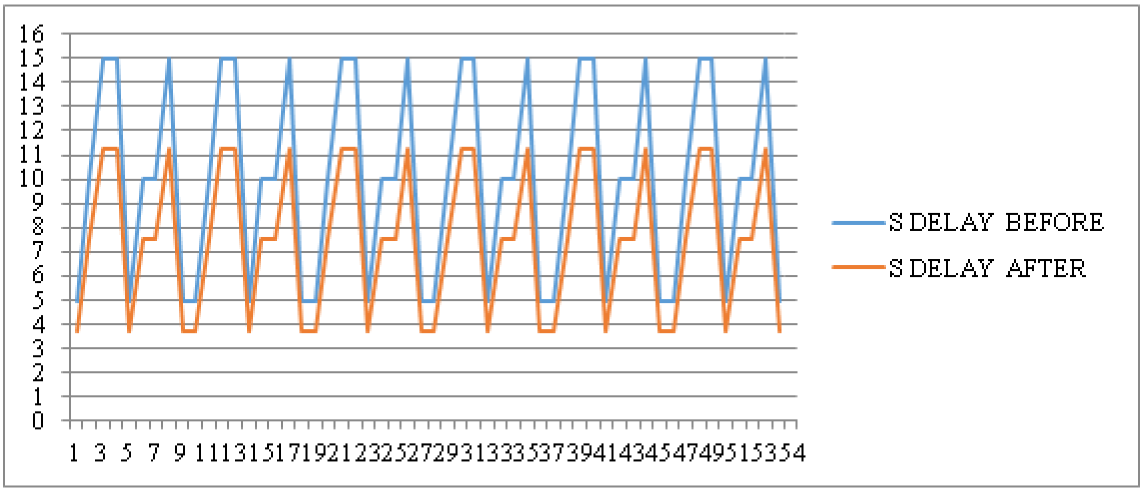

Figure 7: 5 - Kanban's Impact on Supply Delay in the Context of Windows Activity

Moreover, simulation of the electrical activity suggests that the adoption of Kanban's rules would help BCC to reduce delays in the supply of electric components and systems. In the case of electrical activity, the suppliers' delay used to range between 6 days and 12 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the windows activity will fall to below 9 days and can get as low as 4 days (*Refer* to Figure 7:14). Moreover, it usually takes Binladin Construction Company / BCC between 27 days and 55 days to complete all of the electric-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 52 days and can get as low as 25 days. The simulation results also show that Kanban's adoption can help the case-study company to reduce the lead time for the electrical activity by as much as 9%. The scenarios show that the lead time can be as high as 55 days and as low as 25.23 days (*See* Figure 7:13 and Appendix VII – Table 2).

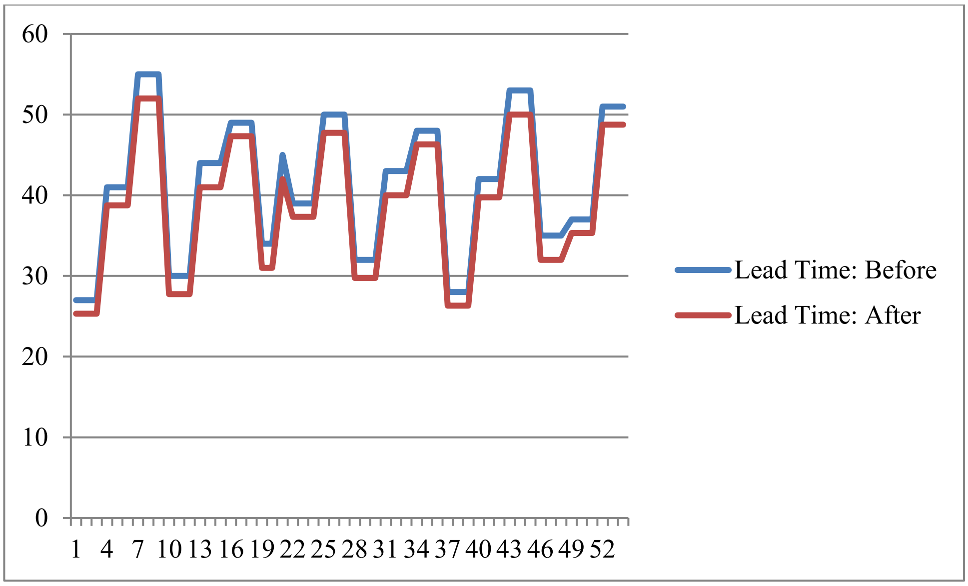

Figure 7: 6 Electrical Lead Time for Before and After Kanban's Adoption

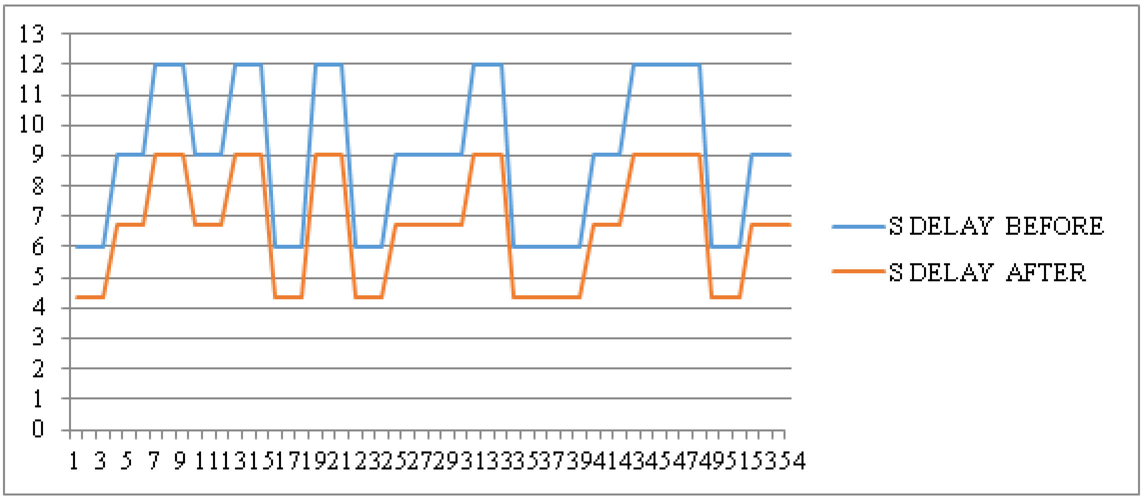

Figure 7: 7 - Kanban's Impact on Supply Delay in the Context of Electrical Activity

Furthermore, in the case of elevators activity, the suppliers' delay used to range between 7 days and 21 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the elevators activity will fall to below 16 days and can get as low as 5 days (*See* Figure 7:16). Moreover, it usually takes Binladin Construction Company / BCC between 28 days and 64 days to complete all of the elevators-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 59 days and can get as low as 26 days. The simulation results also show that Kanban's adoption can help the case-study company to reduce the lead time for the framing activity by as much as 13%. The scenarios show that the lead time can be as high as 64 days and as low as 26.25 days (*See* Figure 7:15 and Appendix VII – Table 3).

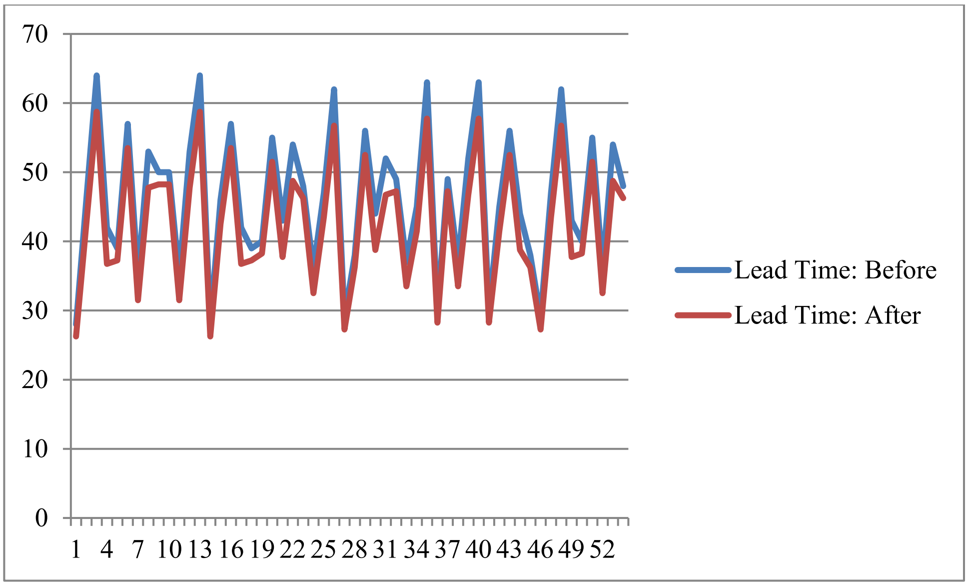

Figure 7: 8 Elevators Lead Time for Before and After Kanban's Adoption

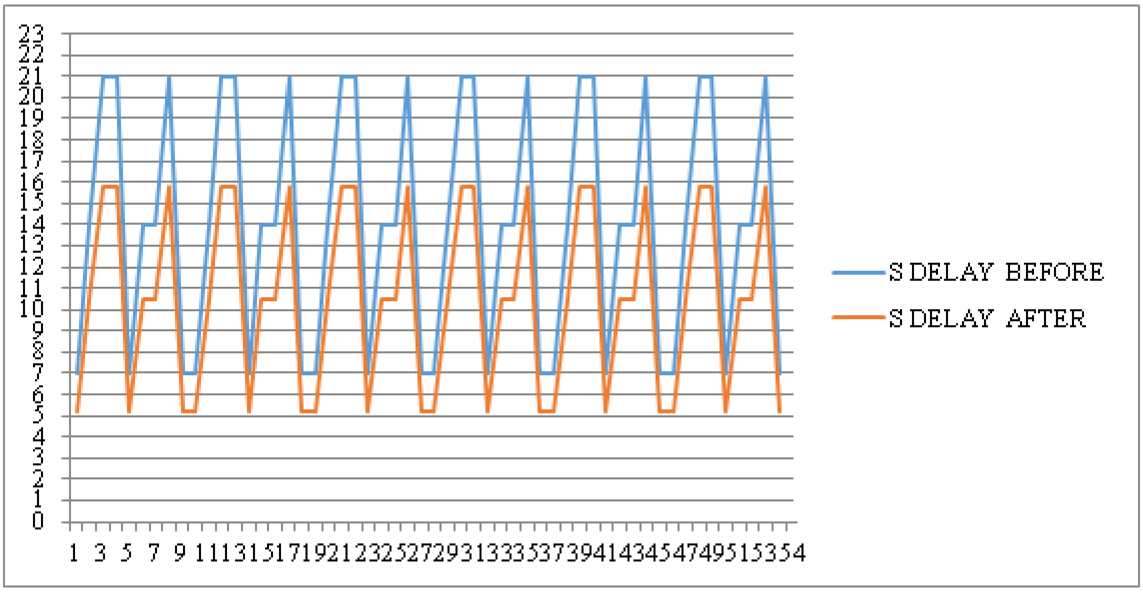

Figure 7: 9 - Kanban's Impact on Supply Delay in the Context of Elevators Activity

Similarly, the SIMIO simulation's output indicates that the adoption of Kanban's 6 rules for the drywall construction activity can help BCC reduce supply delays significantly. In the case of drywall activity, the suppliers' delay used to range between 5 days and 10 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the drywall activity will fall to below 8 days and can get as low as 4 days (*Refer* to Figure 7:18). Moreover, it usually takes Binladin Construction Company / BCC between 18 days and 31 days to complete all of the drywall-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 29 days and can get as low as 17 days. The simulation results also show that Kanban's adoption can help the case-study company to reduce the lead time for the framing activity by as much as 10%. The scenarios show that the lead time can be as high as 31 days and as low as 16.75 days (*Refer to* Figure 7:17 and Appendix VII – Table 4).

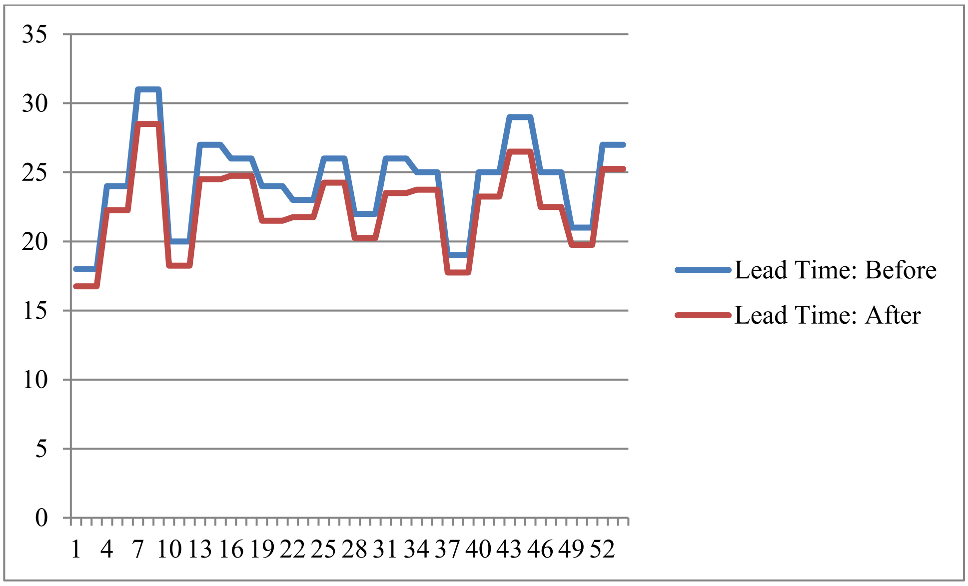

Figure 7: 10 Drywall Lead Time for Before and After Kanban's Adoption

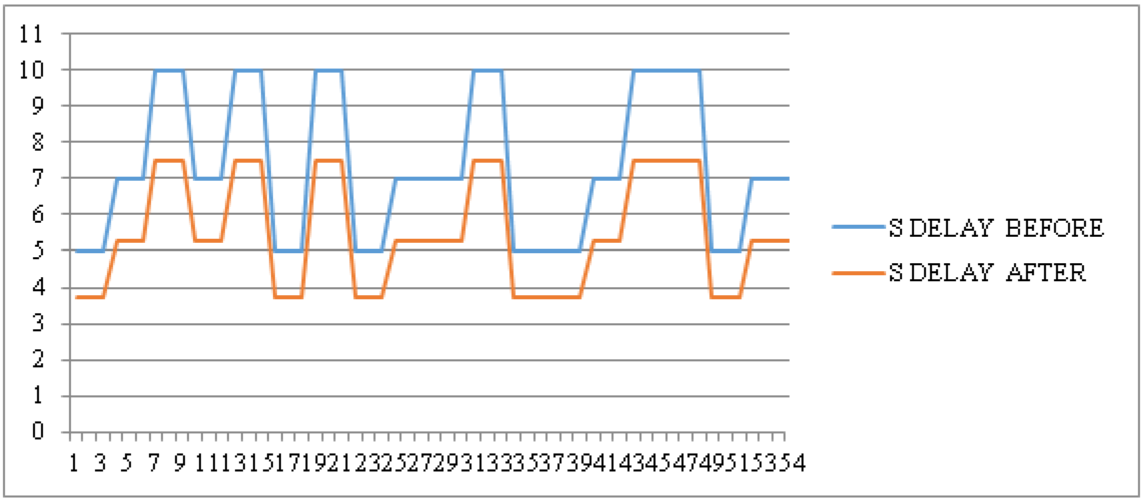

Figure 7: 11 - Kanban's Impact on Supply Delay in the Context of Drywall Activity

Lastly, the SIMIO simulation's output also indicates that the adoption of Kanban's 6 rules for the exterior casework construction activity would enable the Binladin Construction Company / BCC to notably reduce supply delays. In the case of exterior casework, the suppliers' delay used to range between 7 days and 14 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the exterior casework activity will fall to below 11 days and can get as low as 5 days (*Refer* to Figure 7:20). Moreover, it usually takes between 23 days and 44 days for BCC to complete all of the exterior casework-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 41 days and can get as low as 21 days. The simulation results also show that

Kanban's adoption can help the case-study company to reduce the lead time for the framing activity by as much as 12%. The scenarios show that the lead time can be as high as 44 days and as low as 21.25 days (*Refer to* Figure 7:19 and Appendix VII – Table 5).

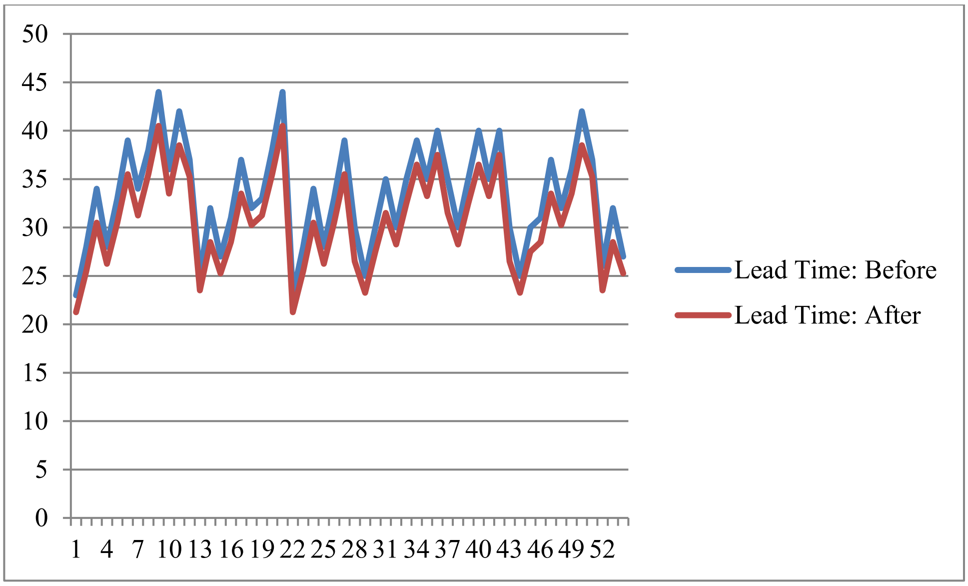

Figure 7: 12 Exterior Casework Lead Time for Before and After Kanban's Adoption

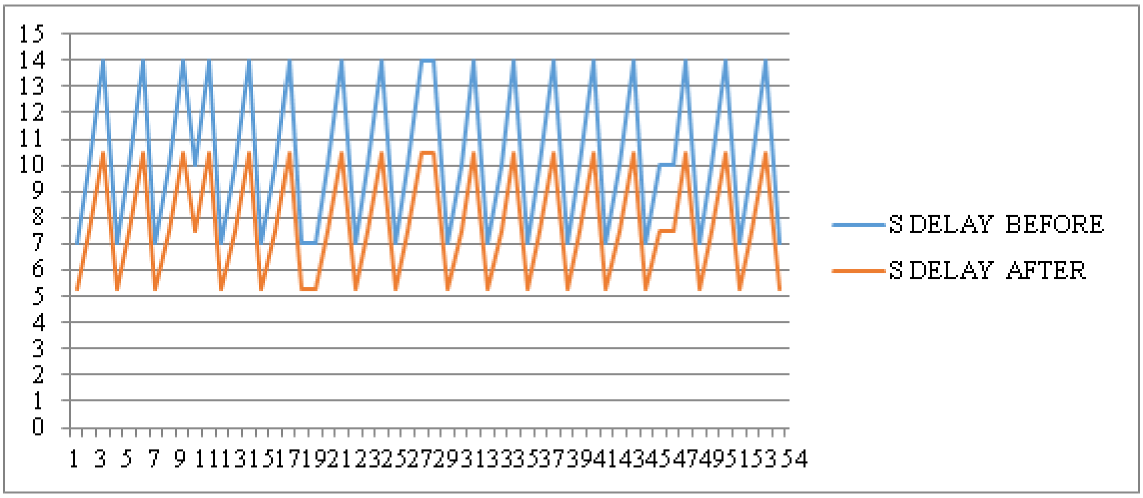

Figure 7: 13 - Kanban's Impact on Supply Delay in the Context of Exterior Casework Activity

7.5 Summary

This chapter demonstrated how the adoption of Kanban's rules could help BCC to significantly improve the operational efficiency of six of its construction activities. It sheds light on some of the operational problems that the firm is currently facing (i.e. current state) and provided suggestions on how the firm could use each of Kanban's six rules to overcome the inefficiencies in its construction activities. It recommends that BCC should: have a strong quality management policy; ensure its downstream processes only pull what they need from upstream operations; ensure that parts are only manufactured when needed and in the right quantities; align the capacities of upstream and downstream processes; fine-tune its upstream and downstream processes; and undertake systematic standardisation of critical processes to sustain stability, consistency, and most importantly high quality.

It is important to note that when Kanban's impact on delay was simulated, the author based the simulation model on the assumption that the efficiency would improve by 10-25%. These improvement percentages had been sourced from other empirical investigations. For example, Hannis-Ansah et al. (2016) explored the benefits of Kanban and concluded that it could help companies to reduce project's lead-times by 10% and improve efficiency by 20%. Another study by More et al. (2016) concluded that the use of Kanban in conjunction with other Lean tools and techniques would help construction firms to improve their operational efficiency by at least 25%. Hence, the author set 10% as the minimum value of improvement and 25% as the maximum improvement potential. However, the simulation model appears to have used the upper limit (i.e. 25%) to simulate most of the scenarios. This explains why the pattern of supply delay estimates for (before) and (after) Kanban's adoption appears somewhat similar. Therefore, it is important that the respective line charts are not interpreted in isolation. Instead, they must be interpreted in conjunction with other outputs such as changes in the lead time of each activity and the reduction in the number of days needed to complete the entire project (i.e. all the activities in the process map).

Chapter 8: Discussion

8.1 Introduction

This research set out to explore how Lean management principles, tools or techniques can help construction project managers to improve the operational performance of construction firms by developing Lean construction framework. This framework has been validated using Binladin Construction Company as a case-study organisation. This aim and all of this research's objectives have been achieved successfully. This chapter demonstrates how the aim and objectives have been achieved. It highlights the research's key findings and discusses them in light of the relevant academic literature. It summarises and evaluates the findings of the empirical investigations and experiments as well as the output of SIMIO 10 simulation of Kanban's impact on the performance of the Binladin Construction Company. It starts with a brief discussion about the applicability of Lean's philosophy in the construction industry. It then discusses the managerial implication of traditional project management practices and the performance-improvement potential of pro-Lean practices before going on to discuss how the adoption of Lean's Kanban can help construction firms address the problem of time and cost overruns. This chapter also provides a justification for the use of computer simulation models to simulate the impact of Kanban's adoption on the time and cost efficiencies of construction activities using real-life scenarios. It briefly discusses the key drivers, enablers and barriers to Kanban in the Saudi construction industry. It ends with statements about the novelty of this research and its limitations.

8.2 Transfer of Lean Manufacturing's Principles for Construction

This research is primarily based on the assumption that Lean's principles, techniques and systems are transferable to the construction industry (*Refer* to Chapter 3). Koskela (1992), who was one of the first scholars who studied the transfer of Lean's principles and systems from manufacturing to construction, argued that the adoption of Lean's principles and systems would help construction firms to not only improve the efficiency of their operations and their overall performance, but also to transform the way processes are managed, value is created and competitive advantage is sustained. Today, the work of Koskela is used as a conceptual foundation for many empirical investigations into the applications and implications of Lean's philosophy in the construction industry (Albalkhy and Sweis, 2020). Alarcon (1997) was also one of the early scholars who advocated the transfer of Lean's principles of construction. In his book titled "Lean Construction", he discussed how Lean thinking could transform the construction industry's outdated approach to production planning and control and more importantly to value creation. For example, he advocated the use of pro-Lean Last Planner System (LPS) to plan and schedule production. LPS is one of the most widely discussed Lean tools in the Lean construction literature. It is typically used by project managers to reduce variability and uncertainty (e.g. AlSehaimi et al. 2014). Lean's 'daily huddle meetings' practice is also used to manage uncertainty and to help project managers deal with unforeseen problems (Li et al. 2019). According to Alarcon (1997), the adoption of Lean helps construction firms to optimise resource allocation through more effective batch-sizing, minimal buffers, reduced inventories, shorter production cycles and more efficient work-in-progress.

This research has found that the use of traditional management systems often hinders Saudi construction firms' abilities to establish effective management processes and procedures. For example, contractors are rarely invited to participate in the planning and development phase, and their involvement is restricted to the construction phase and its associated activities. This outdated approach to construction management results in many missed opportunities and overlooks the contractors' valuable practical insights which are crucial for the development of realistic project plans. It also hinders project owners' abilities to take preemptive actions to prevent costly delays. In contrast, Lean thinking offers a contemporary approach to project management, which has been found to have helped a Saudi construction firm to reduce lead-times and cost and to improve its operational efficiency. This is consistent with many studies that have investigated the adoption of Lean tools and techniques by construction firms (e.g. Thomas et al., 2003; Gonzalez et al., 2010; Bajjou and Chafi, 2020).

This research participants indicated that their company's use of conventional planning and control practices had hindered its ability to establish close, collaborative relationships with its supply chain partners and put a "strain on schedules" which in turn undermined the firm's ability to streamline its procurement operations. They also claimed that the company could develop more effective and realistic plans if it did a better job in terms of "involving trade partners in all stages of the planning process". They believe that greater involvement of key stakeholders in planning processes provides designers and planners with a more detailed insight into the procedural, managerial and operational challenges or issues that could stand in the way of the firm's efforts to complete projects on time and on budget.

Moreover, the participants also indicated that some of Lean's tools and techniques were not only applicable to construction operations, but they could also help construction firms to improve their management effectiveness and operational efficiency (*Refer* to Section 5.3.3 - Table 5:7, Table 5:8 and Table 5:9). For example, most of the participants indicated that Lean helped to "eliminate waste and non-value adding activities" and also "solve potential constructability problems". This means that although many of Lean's tools and techniques are manufacturing-oriented, they could be successfully employed by construction firms to help them with the identification and elimination of operational inefficiencies (i.e. waste). It also means that several of Lean's principles and systems (e.g. Last Planner System) are adaptable and can be modified to satisfy the needs and the operational circumstances of individual construction firms.

8.3 Lean Project Management

This study has explored the concept of 'Lean project management' and the implications of using Lean's tools and techniques to facilitate more effective management of construction projects. The construction industry, not only in Saudi Arabia, but around the world, is having difficulties dealing with the problem of time and cost overruns. In this research, statements of Binladin Construction Company's employees have highlighted a broad range of shortcomings of traditional project management practices (*Refer* to Section 5.2.2). The participants seem to believe that traditional practices are blindsided because they don't account for all of the problems and risks which undermine construction firms' abilities to stay on schedule and on budget. What makes this problematic is that Saudi project managers accept time and cost overruns as part of their reality and don't appear to have the urge to take big, decisive steps to address the root causes of the problem.

Moreover, although the case-study company has adopted a number of important Lean construction practices, its managers have been found to continue to use traditional management practices that provide a simpler means of planning and control (*Refer* to Section 5.2.3). Evidently, the company's top management is frustrated with traditional project management practices mainly because time and cost overruns are costly for all parties involved. Generally, non-excusable delays often carry financial penalties which require contractors to compensate project owners for prolongations. In other words, it is for the benefits of both, contractors and project owners for projects to be completed on time and on budget. So, why Saudi firms have not acted urgently enough to embrace Lean project management systems? There's a perfect answer to this question as the issue is multi-faceted and firms' decisions are often affected by an array of variables. However, one possible answer to this question is that project managers got too comfortable using conventional management practices.

In an attempt to answer this question, the participants had been encouraged to discuss the extent to which conventional planning and control techniques such as CPM help them to deal with delays and to mitigate their risks. There were mixed opinions on its effectiveness. Some participants claimed that it was effective enough for the needs of their company, while others argued that it was only good for relatively smaller, short-term projects. Generally, there was an understanding that CPM and other tools don't offer a perfect solution to the issue of delays. Delays in the construction industry will happen whether one likes them or not. CPM is good for projects that perhaps take less than a year to complete. Projects that take between 2 and 5 years are often characterised by high levels of uncertainty, hundreds of tasks and operational complexity. So CPM will not prepare project managers for these problems, it will only give them an idea of where to focus their attention. Basically, the effectiveness and reliability of conventional project management practices diminish as projects get larger and take longer. So, project managers shouldn't rely on them too much for long-term planning.

Lean project management offers solutions to many of the construction firms' operation problems. It can help them to reduce inefficiencies, boost productivity and maximise value (*Refer* to Section 5.2.4). Also, the use of Lean's principles in construction management enables managers to: maximise performance for the customer at the project level; design products and processes simultaneously; and more importantly exert far greater control throughout the life of the project. The results from the online questionnaire have confirmed a direct link between 'Lean project management' and performance (*Refer* to Section 5.3.6 - Table 5:14 and Table 5:15). More specifically, most of the participants strongly supported the suggestion that Lean project management, improved construction firms' 'operational performance' as well as their overall 'business performance' particularly during planning and execution stages of projects' life cycles.

Concisely, this research has found that Lean management principles and practices boost the effectiveness of project management tools and techniques and redirect them to focus on them on the activities which add the greatest value to project owners and end-users.

8.4 Kanban's Impact of Time and Cost

This research studied the nature of the relationship between the cost and time of construction activities (i.e. framing, windows, electrical, elevators, drywall, and exterior casework) on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand. The author used the Minitab software and ANOVA analysis in particular had been used to explore the nature of relationships between six key construction activities and five performance indicators. The ANOVA analysis enabled the author to assess the statistical significance of the relationships between the two groups of variables. It has been found that the 'processing time' variable has often had a significant impact on almost all of the construction activities under study (*Refer* to Section 6.4). In fact, it has been found to be the single most influential variable in terms of its impact on the cost and time efficiencies of construction activities. It is followed by the 'suppliers' delay' variable. For example, the ANOVA variance analysis for framing actual time shows that processing time, setup time and suppliers' delay all have statistically significant impact of framing time with P-values of 0.000. However, the framing time appears to correlate more strongly with processing time than with suppliers' delay and set up time (*Refer to* Table 6:7 and Figure 6:1). Similarly, the ANOVA variance analysis for framing actual cost shows that worker cost per day, processing time, number of workers and suppliers' delay all have statistically significant impact on actual framing cost with P-values of 0.000, but the actual framing cost appears to correlate more strongly with number of workers than with the other variables (*Refer to* Table 6:8 and Figure 6:2).

Moreover, the author has simulated the improvement potential of Kanban and found that Kanban's six rules could help BCC to reduce delays and optimise the efficiency of its construction operations. The simulation process revealed that the adoption of Kanban's 6 rules of management would help the case-study company to improve the efficiency of its supply chain operations by at least 25% (*Refer* to Section 7.4). For example, in the case of framing, the suppliers' delay prior to Kanban's adoption ranged from 7 days to 15 days. With Kanban, the simulation results indicate that suppliers-caused delays in the context of the framing activity will fall to below 11 days and can get as low as 5 days (*Refer* to Table 7:7). Additionally, it usually takes BCC between 28 days and 58 days to complete all of the framing-related construction tasks, but with Kanban the simulation results indicate that the lead-time will drop below 54 days and can get as low as 26 days.

Furthermore, the findings also suggest that Kanban's adoption would enable BCC to have a strong quality management system that ensures defective components are never passed on to downstream processes. Kanban would ensure that BCC's downstream processes only pull what they need from upstream operations to which should help the firm to avoid overproduction and to reduce costs. More importantly, it would ensure that construction components are manufactured only when needed and in the right quantities, and that capacity of upstream and downstream processes is perfectly aligned. This should help BCC to reduce bottlenecks, avoid backlogs and fine-tune its upstream and downstream processes. Besides, Kanban's use in conjunction with other Lean's tools and systems would facilitate constant identification and elimination of operational waste like 'overprocessing'.

8.5 Enablers, Drivers and Barriers to Kanban's Adoption

This research involved the collection of qualitative and quantitative data regarding the most impactful drivers, enablers and barriers to Kanban's adoption. The data were collected using both interviews and web-based questionnaires. The data highlighted several vital themes. First, there were claims that the firm's performance would continue to deteriorate unless it further optimises its planning operations (*Refer* to Section 5.2.1). The participants believe that the need to improve operational performance was one of the main drivers of Lean construction practices' adoption. They advocated substituting the conventional paper-based project management tools with modern real-time planning and control techniques. They indicated that lack of real-time feedback meant that information sharing was often 'unsystematic' and 'sporadic' which in turn undermined their company's ability to achieve high operational performance. The participants' responses to the survey also indicate that Saudi construction firms are typically driven to adopt pro-Lean practices by the need to reduce waste (i.e. inefficiencies), improve problem-solving activities and optimise the effectiveness of communication between and across teams (*Refer* to Section 5.3.3).

Second, workers of the case's firm have been found to have a positive attitude towards Lean and supported the idea of using Lean management practices to help project managers to reduce costs and improve quality. They often linked Lean to improvements in efficiency, quality and most crucially to cost savings. It appears that their perceptions are shaped by Lean's positive contributions to the firm's performance, such as; better communication, closer collaboration, fewer defects, improved quality and better bottom-line results. They believe that the positive impact of pro-Lean practices is very clear in the areas of design, project management and organisational management (*Refer* to Section 5.3.3 - Table 5:7, Table 5:8 and Table 5:9). In the area of design, Lean typically improves constructability of proposed designs, facilitates adoption of state-of-the-art technologies, boosts quality and minimises non-value-adding design features or attributes. In project management, Lean is commonly associated with improvements in reduced lead-time, optimised cost, reduced safety and environmental risks, and greater standardisation of processes and procedures. In organisational management, the participants indicated that Lean practices help to increase staff motivation, closely integrate supply chain operations and increase awareness of non-value-adding activities or inefficiencies.

Third, the data highlighted a variety of drivers which included: greater value for money; greater returns on investment; better quality; higher efficiency; reduced cost; improved public image; reduced disruptions and fewer unnecessary delays (*Refer* to Section 5.2.2 and Section 5.3). Generally, Lean construction is associated with a wide variety of benefits which encourage senior managers to decide in favour of adopting pro-Lean initiatives. For example, the participants explained that BCC's senior management was very interested in the pro-Lean practices which could help them to reduce cost of operations and to deliver greater value to their clients. This research has confirmed what's already been reported in the construction management literature with regards to the drivers of Lean construction, but found that Saudi construction firms tend to be more interested in cost reduction than in value maximisation. They work hard to satisfy clients' needs and expectations, but their attention is rigidly focused on cutting costs and profit maximisation. That's another reason why the Saudi construction industry really needs to embrace the principles and tools of Lean construction. Lean would help Saudi firms find the right balance between quality and profitability and to reduce cost without compromising end-products' quality.

Fourth, in terms of enablers, the data indicated that the success of any Lean construction initiative depends heavily on senior management's commitment and willingness to allocate the needed resources and personnel to implementation projects. The participants also think that on-site training and better understanding of the principles of Lean thinking to be critically important (*Refer* to Section 5.2.6 and Section 5.3.5). They also stated that having good systems of communication and knowledge sharing motivates workers participate in implementation efforts and to be more involved in their company's problem-solving and solution-finding efforts. Evidently, the interviewees stressed the significance of attitudinal and behavioural factors which they believed have a direct impact on workers' willingness to support and participate in the implementation and operationalisation of Lean initiatives. For example, one interviewee argued in favour of having a good reward system and rewards that are good enough to incentivise workers and to encourage them to continue to perform well. He claimed that without very good incentive mechanisms, the managers would find it very difficult to boost participation and to convince workers to engage more actively with pro-Lean initiatives. Additionally, the survey data show that regular training and effective change management processes and procedures are highly important enablers of Lean construction tools and techniques. In fact, the participants overwhelmingly agreed with the suggestion that "regular training of workforce" was an important enabler of Lean construction practices (*See* Table 5:13).

Fifth, the data highlighted several barriers that Saudi construction firms commonly face during the implementation of Lean's principles. These included: cultural resistance, short-sighted investment policies, lengthy implementation timeline, costly implementation processes, managers' impatience, lack of knowledge and skills, complexity and lack of workers' buy-in (*Refer* to Section 5.2.7). Senior managers' short-sighted investment policy has been identified as a significant barrier to Lean construction practices. Moreover, the firm's managers seem to accept 'delays' and schedule updates as reality and that there isn't so much they can do to eliminate the risk of time and cost overruns. They instead focus their energy on ensuring that their plans are as realistic as possible and that contingency plans are devised to deal with unforeseen issues that may disrupt operations and undermine the firm's ability to stay on schedule and on budget.

Moreover, not all of the employees were interested in the adoption of pro-Lean practices. The interviewees claimed that there were people who opposed the idea of standardisation which necessitates that every activity a worker does have to follow pre-defined procedures. This claim indicates two significant issues. First, managers seem to have failed to secure workers' buy-in and commitment to Lean's principles and practices. Second, organisational resistance to Lean's implementation exists, at least implicitly. Both issues are often linked to 'change management' failure and this means that unless they are adequately addressed, they would almost certainly hinder Saudi construction companies' abilities to successfully implement and actualise the principles and practices of Lean construction. To make things worse, the interviewees identified 'lengthy implementation timeline' and 'misunderstanding of Lean's principles' as common barriers to pro-Lean initiatives. The earlier issue indicates short-termism while the latter highlights lack of awareness which, when combined together create an organisational climate that's characterised by scepticism and resistance.

This research has also found that the adoption of pro-Lean practices may also be hindered by external factors (*Refer* to Section 5.3.5). The participants' responses to the questionnaire suggest that 'government bureaucracy and instability' are responsible for the construction industry's lacklustre approach to the adoption and implementation of Lean practices. This means that Saudi construction firms need to be encouraged, or pushed, by governmental agencies to embrace the principles of Lean construction. The government's involvement would help to create a level-playing field and facilitate mass-adoption of Lean.

Interestingly, this research's findings are consistent with the conclusions of several other empirical studies. For example, Sarhan et al. (2018) investigated Lean construction's barriers in the context of the Saudi construction industry. Their investigation identified 22 influential barriers that had, for many years, undermined the industry's efforts to achieve widespread adoption of Lean's tools and techniques. Their list of barriers included: lack of management commitment, workers' resistance, cultural incompatibility and inadequate training. The issues of cultural resistance and lack of training have also been identified by Shang and Pheng (2014). What's different, however, is that this research has found that the success of Lean construction is contingent upon a broad variety of internal and external factors. Also, different stakeholders, internal and external, have varying degrees of impact on the implementation process of pro-Lean tools and techniques.

8.6 Novelty of Research

The novelty of this research is centred on develop a lean project management framework; using Kanban's six roles, simulation modelling and process mapping, all to identify the factors that benefit and prevent its implementation.

This research is evidently novel despite the fact that the principles of Lean management can be traced back to the late 1930s. Back then, Taiichi Ohno, a Toyota engineer, began to develop a set of standardised systems and processes with the hope of improving flow, efficiency, quality and most importantly product variety (Womack and Jones, 2003). He built what was known as the Toyota Production System or TPS. This system did not receive any scholarly attention until the mid 1990s and only after Womack et al. (1990) published their book titled "the machine that changed the world".

The novelty of this research is centred on the use of Kanban's six roles of management to address the problem of delay in the Saudi construction industry. The idea of using Lean tools and techniques for construction project management is not new at all, but what makes this study novel is that it contributes to a very niche and an underdeveloped research subject in the field of construction management. Lean construction, as concept, was first considered by Koskela (1992) in his research titled "application of the new production philosophy to construction". It received greater attention when, in 1993, the International Group for Lean Construction (IDLC) was established. Its popularity grew further after the first Lean Construction Institute was incorporated by Glenn Ballard and Greg Howell in 1997. Since then, researchers have been studying the benefits and use of various Lean tools and techniques in construction projects. However, despite its rapid growth, this area of research is still developing. Hence, this research has been conducted with the intention to advance our knowledge and understanding of not only the benefits, enablers and barriers of Lean construction adoption, but also of how Lean's tools and techniques may help address the problems of delays and cost overruns in construction projects. This research's findings are generally consistent with the propositions of Koskela (1992) especially with regards to efficiency improvements. The findings indicate that there is a direct link between Lean Construction's adoption and improvements in operational efficiency, organisational effectiveness and more importantly in cost savings. The participants believe that Lean has made numerous positive contributions to their company's performance, such as better communication, closer collaboration, fewer defects, improved quality, stronger stakeholder relationships and most importantly greater bottom-line results.

Moreover, this research's findings also further improve our knowledge and understanding of how the adoption and operationalisation of Kanban's six principles of management may help to improve the cost and time efficiencies in construction projects. The results indicate that the use of Kanban would help Saudi construction firms to improve their efficiencies by as much as 25%. This will be achieved by (1) improving quality management processes; (2) streamlining of upstream and downstream operations; (3) using pull-based production and supply chain management systems; (4) aligning demand with operational capacity; (5) fine-tuning upstream and downstream activities; and (6) standardising critical processes.

Another important element, which makes this research novel, is the development of a new, contemporary project management framework that incorporates Kanban's principles into the management systems and processes of construction projects. The development process of the proposed framework was systematic and based on existing theories and concepts. It involved the use of process mapping, Taguchi technique, and simulation modelling in order to demonstrate the impact of Kanban's rule's adoption on the performance of Saudi firms. Moreover, the proposed framework is different from existing models and other frameworks. It does not only illustrate how the adoption of Lean's principles, tools and techniques can help construction firms to improve their performance, but it also focuses specifically on addressing the problem of delays and cost overruns. It provides a roadmap which details how the use of Lean construction's tools like Kanban can improve construction projects' cost and time efficiencies. It also demonstrates, using Lean's Kanban, how upstream and downstream operations can be streamlined in order to improve efficiency. Unlike other frameworks, it focuses more on what really needs to be done in order to improve firms' operational efficiencies than on the lifecycle of adoption processes. It is problem-oriented and facilitates the development of well-thought action plans which can be used to identify and eliminate the root causes of operational inefficiencies.

This research should also be seen as an attempt to address the shortcomings and limitations of traditional project management tools and techniques which are still widely used in the Saudi construction industry. The limitations include, but not limited to; overreliance on linear and static planning methods, poor integration of supply chain operations, and inefficient deployment and utilisation of resources. For example, the participants claimed that their company's failure to establish close relationships with its supply chain partners put a "strain on schedules" and also hindered its ability to streamline its procurement operations. They also blamed traditional project management practices for their inability to account for all project risks, coordinate construction activities effectively, and allocate resources efficiently.

Moreover, although this research is not the only study that investigates the limitations of traditional project management practices, its findings contribute to researchers' efforts to understand Lean implementation's benefits, enablers, barriers and implications. The findings are consistent with the findings and arguments of many other researchers and Lean construction scholars. For example, Shaqour (2021) investigated Lean construction's adoption in Egypt. He found that although Lean tools and techniques were perceived to bring many benefits such as "improve process control, improved planning, material storage control (access and inventory) and time reduction" (p. 1), their adoption had been really slow. Shaqour attributed the slow uptake primarily to lack of knowledge and understanding.

Similarly, Xing et al., (2021) investigated the implementation of Lean construction methods and techniques in the China using a case-study approach. They found that uptake of Lean construction by Chinese firms was not as fast and widespread as it should despite its many benefits. They concluded that "project waiting times and defects can be greatly reduced through the implementation of LC, and that improvement of construction workflow along with project productivity and quality were the two most valuable benefits of using lean practices; there was also a consensus that lack of trust and the abilities of stakeholders are the biggest challenges" (Xing et al., 2021, p. 1). Another study by Aslam et al., (2021) also studied the adoption of advanced project management practices; namely "lean project delivery system". They found that "despite enormous benefits, the construction industry is struggling with effective implementation of LPDS especially in achieving Lean construction principles like improving the visualization and maintaining effective flow of information" (p. 1).

This research also explores the transferability of Lean tools and techniques, particularly Kanban, to the Saudi construction industry. It's been found that Lean isn't only transferable to the construction industry, but also hugely beneficial. The participants highlighted a variety of benefits which encouraged the case company to embrace the principles of Lean construction. The identified benefits included: greater value for money; greater returns on investment; improved quality; improved operational efficiency; reduced cost; higher client satisfaction levels; and most importantly reduced disruptions and unnecessary delays. The findings provide a strong defence against arguments which purport that Lean tools and techniques are manufacturing-centric and inconsistent with the nature of construction operations. For example, Kanban is seen as manufacturing-centric because it facilitates pull-based production and streamlining of supply chain operations. Perhaps this is why it has not been adopted as widely as other Lean tools and techniques. This research's findings therefore advance our understanding of how Kanban's six roles of management can be used by construction firms to improve their time and cost efficiencies. The author hopes that his findings will encourage more researchers to explore the transferability of Kanban and other 'manufacturing-centric' Lean tools and techniques to the construction industry.

Moreover, this research contributes to an uncoordinated effort to advocate the transfer of all of Lean management's tools and techniques to the construction industry. For example, Aureliano et al. (2019) explored the applicability of different Lean manufacturing's practices to construction management and concluded that it was counterintuitive to dismiss the usefulness of efficiency-improving project management practices just because they had been developed in a sector other than construction. They argued that it was time to break free from the "old paradigms" and to embrace Lean and all of its tools, techniques, systems and principles. Their investigation found that Lean could help construction firms to reduce cost by as much as 9%.

There are a few studies which have a similar investigative approach to this research, but they study the improvement potential of Lean tools and techniques other than Kanban. For example, Zahraee et al. (2021) studied the use of 'value stream mapping' to improve the efficiency and productivity of concrete pouring processes. Their simulation results showed that the implementation of Lean management principles in general and the use of value stream mapping in particular would get the "production lead time (PLT) reduced from 11 days to 7 days, and the value-added time decreased from 38.2 min to 22.5 min. Takt time also was reduced from 138 s to 93 s" (p. 1279). Similarly, a study by Singh et al. (2021) investigated the use of Lean management techniques such as the Last Planner System (LPS) to improve the efficiency of construction operations. Their analysis revealed that more than 90% of participants considered the use of Lean's Big Rooms, 5S and LPS techniques to be very important and effective in boosting projects' efficiency, productivity and outcomes.

This research is different in many ways from other empirical studies that investigate the benefits and implications of Kanban in the context of the construction industry. Firstly, it uses Kanban as a means of improving operational efficiency and addressing the problem of delay in the context of a large Saudi construction firm. Secondly, it simulates the impact of Kanban's adoption using scenarios of six important construction activities. A recent re-review of relevant literature has confirmed that there have not been any studies that investigate the use of Kanban in the context of Saudi construction firms or the context of the activities this research investigates. Thirdly, other researchers have not studied the improvement potential of Kanban as thoroughly as this research. Their investigations lack depth and only study Kanban's benefits and implications in conjunction with other Lean tools and techniques. For example, Xing et al. (2021) studied the adoption of Lean techniques in Chinese projects. Their investigation found that although Kanban could play a" vital role in improving the workflow and visualization of the construction process" in China's ACE industry, the system is "rarely used" (p. 12). They attributed the slow rate of adoption to lack of awareness of Kanban's many benefits. Another study by Ko and Kuo (2015) also investigated the implementation of Lean techniques to help improve formwork construction activities. They found that using Kanban in conjunction with other Lean tools such as Andon would help construction firms to reduce waste and boost the efficiency of their formwork construction operations. Their results show that Andon and Kanban could help to eliminate "437.28 wasted worker-hours in the formwork assembly and machining process, raising productivity from an initial 11.72 square meters per worker per day to 19.18" (p. 456). Similarly, Si et al. (2021) explored the use of Kanban with Just-in-Time (JIT) to improve the efficiency and productivity of off-site construction operations. Their analysis revealed that "component delivery waste in off-site construction supply chain results from the mismatch between the scheduled delivery date and the actual optimal delivery date" (p. 5). They concluded that "Kanban can reduce or eliminate overproduction (more or earlier than actually needed) waste to achieve just-in-time production" (p. 5).

8.7 Contributions to Knowledge

This research makes several valuable contributions to knowledge. These include:

1. This research has demonstrated the positive improvement potential of Kanban's rules of management in the context of the Saudi construction industry. It applied Kanban's rules to six different construction activities and examined their impact on the time and cost efficiencies of each activity. To the best of the author's knowledge, there are not any other empirical studies in the literature that have explored the same issues.
2. This research has identified the variables or factors that contribute to the problem of delays in the Saudi construction industry. The findings are quite unique and the author hasn't come across similar conclusions despite the thorough review of all relevant academic publications - this research found that the 'processing time' variable has a significant impact on almost all of the construction activities under study. In fact, it has been found to be the single most influential variable in terms of its impact on the cost and time efficiencies. The 'suppliers' delay' is the second most impactful variable.
3. This research broadens our understanding of the synergies which exist between the principles of Lean manufacturing and construction project management. It advocates the transfer of Lean's principles to the construction industry and encourages project managers to embrace Lean's tools as a means of overcoming the weaknesses and shortcomings of conventional project management practices.

4. This research sheds light on the operational problems that Saudi construction firms are currently facing or struggling with. It also highlights the drivers, benefits, enablers and barriers to the implementation and operationalisation of Lean's principles in the operational context of Saudi construction firms. It provides an insight into what the Saudi construction industry is going through and would happen if Saudi construction firms begin mass-adoption of Lean's tools and techniques, particularly Kanban.
5. Although there are numerous studies that investigate the impact of Lean construction's tools and techniques on performance, this research approach is unique in the sense that it focuses on cost overruns and delays as problems and considers Kanban as potential solutions. It also uses modelling software to simulate the impact of the proposed solutions for a Saudi firm's operational performance.
6. This research also contributes to the project management literature as it considers the use of Lean management tools and techniques as a substitute to the outdated project management practices to achieve better results. It also contributes to the Lean construction literature as it explores the experiences of Saudi construction firms with the adoption and utilisation of Lean's tools.
7. This research contributes to the ongoing debate about the applicability of Lean's tools and techniques to the operational context of the construction industry. It doesn't only study the benefits, implications, enablers and barriers of Lean construction, but it also advocates its diffusion among Saudi construction firms.

8.8 Research Limitations

Like any other empirical investigation, this research has some limitations. First, the research has been based primarily on a single, large Saudi construction firm - Binladin Construction Company or BCC. It isn't uncommon for interpretivist researchers who investigate the impact of Lean's principles on the operations of construction firms to use a single case study, but this approach restricts the generalisability of research findings. In other words, this study's results don't necessarily apply to other Saudi construction firms and probably don't apply to firms in other countries, especially if their operations aren't based in the Middle East.

Second, Lean manufacturing has many tools, techniques and systems that are transferable to the construction industry and which could help Saudi construction firms to overcome some of their inefficiencies, but this research only considered the impact of Kanban's adoption on the time and cost efficiencies on a small group of construction activities. This study would have made a greater contribution to the Lean construction literature and would have offered greater value to the practice of project management had it only considered the impact of other Lean's tools/techniques on BCC's operational performance as demonstrated by Kanban's adoption in Chapter 7.

Third, the number of people who have been interviewed for this research isn't big enough. It wasn't easy at all to convince employees of BCC to make the time and effort to participate in this research. Despite the author's attempts, only a handful of people agreed to participate. On the other hand, the author has been able to collect the right type of data in the right volumes to satisfy the data requirements of this research.

Fourth, although the use of online, self-administered questionnaires provide researchers with a convenient, cost-effective and efficient strategy for the collection of primary data, this approach has been criticised for lack of robust and high risk of bias. It is said that the use of self-report surveys are exposed to higher risk of social desirability bias as participants find themselves inclined to pick the responses that are socially desirable rather than stating what they really think about the issues under investigation.

Fifth, the use of computer software to simulate the impact of Lean's tools and techniques to the performance of construction firms, provides an incomplete and an inaccurate reflection of their potential benefits as well as their operational implications. The software relies on estimates and pre-defined assumptions which more often than not fail to account for the complex and dynamic nature of construction operations.

8.9 Summary

This chapter demonstrated how the research's aim and all of objectives have been achieved. It highlighted the research's key findings and discussed them in light of the academic literature. It discussed some of the synergies which exist between Lean manufacturing and construction management and provided evidence that confirms the applicability of Lean's philosophy in the construction industry. It also highlighted the weaknesses and shortcomings of traditional project management practices and encouraged project managers to consider the improvement potential of pro-Lean practices. It discussed how the adoption of Lean's Kanban can help Saudi construction firms address the problem of time and cost overruns. Last but not least, it emphasised on the importance of senior management commitment, workers' buy-in and good training for the success of pro-Lean tools' and initiatives' implementations.

Chapter 9: Conclusions

9.1 Introduction

This chapter summarises the research's main findings and demonstrates how the research's aim and objectives have been successfully achieved. The research's primary purpose has been to improve the operational performance of Saudi construction firms through Lean project management and to develop a Lean project management framework which they can use to improve the time and cost efficiencies of their construction operations. Thus, the author has explored the applicability of Lean management principles, tools or techniques to the construction industry in general and to Saudi construction firms in particular. This chapter presents the outcome of his exploratory investigations. It's structured by objective.

9.2 Conclusions

9.2.1 Objective 1: Operational Problems of Saudi Construction Firms

It has been found that construction firms in Saudi Arabia are struggling with the management of delays and that their activities are characterised by cost and schedule overruns (*See* Section 5.2). In order to address this problem, this research firstly examined the nature of the relationship between the cost and time efficiencies of construction activities (i.e. framing, windows, electrical, elevators, drywall, and exterior casework) on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand (*See* Section 6.4). It has been found that the 'processing time' variable has often had a significant impact on almost all of the construction activities under study. In fact, it has been found to be the single most influential variable in terms of its impact on the cost and time efficiencies of construction activities. It is followed by the 'suppliers' delay' variable (*Refer* to Table 6:19 and Table 6:20 in Section 6.5).

Secondly, this research explored how the adoption of the principles of 'Lean Construction' and Kanban's 6 rules in particular could solve some of the current problems of Saudi construction firms. For example, conventional construction logistics, lack a flow view and the ability to rapidly and precisely acquire data that's needed to optimise planning activities, control systems and logistical operations. To overcome such problems, Kanban enables firms to switch from push-based systems to pull-based systems which involve real-time monitoring of consumption and demand-triggered replenishment. This study simulated the potential of Kanban and found that the adoption of Kanban would help Saudi firms to reduce delays and optimise their operations' efficiency (*Refer* to Section 7.4).

9.2.2 Objective 2: Efficacy of Traditional Project Management

It has been found that conventional project management tools are becoming increasingly ineffective, especially when employed in isolation. Although traditional project planning approaches facilitate multi-project planning, they rely on deterministic activity task durations and do not support what-if analysis without which the causal relationships among the different activities and associates constraints can't be understood.

Moreover, the use of traditional management practices has hindered Saudi firms' abilities to establish more effective management processes. For example, contractors are rarely invited to participate in the planning and development phase, and their involvement is restricted to the construction phase. This outdated approach to project management results in many missed opportunities and overlooks the contractors' valuable practical insights which are crucial for the development of realistic project plans. It also undermines project owners' abilities to take preemptive actions to prevent costly delays.

Furthermore, this research has examined the nature of the relationship between the cost and time of construction activities on one hand and worker cost per day, processing time, setup time, number of workers and suppliers' delay on the other hand using the Minitab software. The simulation results indicate that the 'processing time' variable has often had a high statistically significant impact on almost all of the construction activities under study. In fact, it has been found to be the single most influential variable in terms of its impact on the cost and time efficiencies of construction activities.

9.2.3 Objective 3: Obstacles to Optimal Operational Performance

This research has discovered a range of factors that stand in the way of Saudi construction firms' performance improvement efforts. First, the participants stated that their operational performance would improve significantly if managers abandoned the use of "paper-based tools" in favour of real-time planning and control techniques. There were major planning and control deficits between the case company's current performance and that of international construction firms. Second, it has been found that although the conventional project management practices, provides construction firms with good means of controlling costs and reducing the risk of delays, they aren't effective in dealing with many of today's management challenges. In fact, it has been found that conventional practices could restrict management's ability to account for all project risks, to coordinate construction activities effectively, to allocate resources efficiently and most importantly to prevent time and cost overruns (*Refer* to Section 5.2.2).

In terms of benefits, Lean is perceived as an effective management tool which can help project managers to reduce costs and improve quality. Lean's principles are often linked to improvements in operational efficiency, management effectiveness and most crucially with cost savings. It has been found that the participants' perceptions are shaped by Lean's positive contributions to the company's performance, such as better communication, closer collaboration, fewer defects, improved quality, stronger stakeholder relationships and most importantly greater bottom-line results. The participants also claimed that their company was driven to embrace Lean by its broad set of benefits; namely, greater value for money; higher returns on investment; improved quality; improved operational efficiency; reduced cost; higher client satisfaction levels; improved public image; and most importantly reduced disruptions and unnecessary delays.

In terms of enablers, this research has found that the success of Lean construction initiatives depends heavily on senior management's commitment and motivation to allocate the needed resources and the right personnel to the implementation teams. This research has also discovered numerous barriers which affect the implementation of pro-Lean initiatives; including: cultural resistance, short-sighted investment policies, lengthy implementation, costly processes, managers' impatience, lack of knowledge and skills, complexity and lack of workers' buy-in. Senior managers' short-sighted investment policy has been identified as the most significant barrier to Lean construction.

9.2.4 Objective 4: Lean Project Management

This research has found a range of similarities and differences between the operational contexts of manufacturing and construction industries. In terms of similarities, both manufacturing and construction firms produce tangible products whose quality can't be too difficult to examine, monitor and control. Also, both industries' performance, especially in terms of operational performance is affected by the characteristics of the workforce. Moreover, the concept of 'value' is somewhat the same in both industries. Manufacturers and construction firms view 'value' as a reflection of their abilities to meet their customers' pre-defined set of specifications and expectations.

On the other hand, construction operations are far less standardised than manufacturing activities and that makes it difficult to apply Lean's principles to construction firms, especially since the philosophy relies heavily on standardisation of processes as a quality management strategy. More importantly, manufacturing operations are characterised by continuity and predictability, whereas construction firms more often than not work on one-off projects or prototypes. However, despite the differences between the two industries' operations, this research has found that Lean's principles are transferable to the construction industry. Lean offers a contemporary approach to project management, which has been found to have helped Binladin Construction Company reduce lead-times, minimise cost and improve efficiency.

9.2.5 Objective 5: Improvements

Based on these six rules of Kanban and this study's findings, the author has produced the following improvement strategies / recommendations:

1. Saudi construction firms should have strong quality management policies that ensure that defective components are never passed on to downstream processes.
2. Saudi construction companies' project managers should ensure that downstream processes only pull what they need from upstream processes to reduce the risk of overproduction and also to reduce unnecessary/avoidable costs.
3. Saudi construction companies' project managers should make sure that construction parts are only manufactured when needed and in the right quantities.
4. Saudi construction firms should align the capacities of upstream and downstream processes, reduce bottlenecks and avoid backlogs.
5. Saudi construction firms should fine-tune their upstream and downstream processes through the continuous identification and elimination of operational waste such as unnecessary processing and waiting time.
6. Saudi construction firms should embark on a journey of systematic standardisation of construction processes and procedures to ensure good levels of stability, consistency, predictability and most importantly high quality.

9.3 Future Research

Future research should address the limitations of this research. For example:

- This research has been based primarily on a single case study of a Saudi construction firm. It isn't uncommon for interpretivist researchers who investigate the impact of Lean's principles on the operations of construction firms to use a single case study, but this approach restricts the generalisability of research findings. In other words, this study's results don't necessarily apply to other Saudi construction firms and probably don't apply to firms in other countries, especially if their operations aren't based in the Middle East. Therefore, future research should consider involving multiple firms from different countries or continents in order to produce generalisable results that can be used to develop implementation theories or models for Lean construction.

- Lean manufacturing has many tools and rules that are transferable to the construction industry and which can help construction firms to overcome their inefficiencies, but this research only considered the impact of Kanban's adoption on the time and cost efficiencies on a small group of construction activities. Therefore, further research is needed into the impact of other Lean's tools and techniques for the timelines and cost of construction projects. Researchers can even explore the impact of Kanban's rules on the operational performances of construction firms when used in conjunction with other Lean's tools and techniques. This would enable researchers to make a greater contribution to the Lean construction literature and would offer greater value to the practice of project management.
- The number of people who have been interviewed for this research isn't big enough. Future research should consider using a much larger research sample. For interviews, a sample of at least 20 project management practitioners would provide a good insight into the real circumstances under which construction firms operate and also highlight in greater detail Lean's challenges as well as the success factors.
- This research adopted a cross-sectional, single case-study strategy. This strategy only provides a snapshot of what construction firms struggle with and how Lean's adoption helps them overcome some of their operational problems. Therefore, researchers are recommended to adopt an 'action research' strategy in order to immerse themselves far deep into the operational contexts and circumstances of construction firms' journeys towards Lean construction. Action research helps researchers to provide a richer and much deeper insight into the firms' experiences.

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11. Appendices

11.1 Appendix I: Research Questions

Research Questions	Research Objectives
What are the operational challenges that construction firms in general, and Saudi construction firms in particular are facing?	**Objective 1:** To identify the operational challenges faced by Saudi construction firms related to cost and time overruns through critical literature evaluation.
What are the project management tools and techniques which construction firms in general and Saudi construction firms in particular use for planning, control and management of construction activities?	**Objective 2:** To evaluate the efficacy of traditional project management tools and techniques in terms of helping construction firms to reduce costs and prevent unnecessary delays through critical analysis of relevant, peer-reviewed publications and through semi-structured interviews with construction project management practitioners.
What are the factors that undermine the performance of construction firms?	**Objective 2:** To evaluate the efficacy of traditional project management tools and techniques in terms of helping construction firms to reduce costs and prevent unnecessary delays through critical analysis of relevant, peer-reviewed publications and through semi-structured interviews with construction project management practitioners.
How could the principles of Lean construction help Saudi construction firms to address their operational challenges, especially in relation to the cost and delay?	**Objective 4:** To examine the synergies, which exist between the principles of Lean management and construction project management practices by analysing the current state of the Saudi Binladin Construction Company using process mapping, Discrete Event Simulation (DES) and Taguchi orthogonal arrays.
What are the implementation enablers and barriers that have been experienced by Saudi construction firms when trying to implement Lean construction techniques?	**Objective 3:** To identify the main factors, benefits, barriers and enablers of Lean construction through both semi-structured interviews and close-ended questionnaire.
What are the benefits and operational implications of Lean construction adoption in the context of Saudi construction firms?	**Objective 3:** To identify the main factors, benefits, barriers and enablers of Lean construction through both semi-structured interviews and close-ended questionnaire.
How the adoption of Lean construction's tools and techniques could affect the operational performance of construction firms?	**Objective 5:** To improve the current state of Binladin Construction Company's operations with a focus on time and cost efficiencies using Lean tools to develop the framework.

11.2 Appendix II: Questionnaire

The questionnaire examines the impact of lean project management on construction projects and how it can help the construction industry improve the delivery process of projects.

Please mark boxes as follows ☒

Section 1: General Information

1. Name of organisation (optional)
…………………………………………………………………………………………...........................
....

2. Number of employees

☐ Up to 50 ☐ Up to 250 ☐ Above 250

3. Position of respondent………………………………………………………………………..

4. Your profession

☐ Civil Engineer ☐ Architect ☐ Quantity Surveyor

Othes, specify…………..

5. How long have you worked in the construction industry?

☐ 1 year to 5 years ☐ 6 years to 10 years ☐ 11 years to 15 years

☐ 16 years to 20 years ☐ 21 years to 25 years ☐ Over 25 years

6. What is the main activity of your business?

☐ Design
☐ Construction
☐ Both design and construction

7. Did you study any project management courses? Yes ☐ No ☐

8. If yes, what courses? ☐

9. How do you evaluate your knowledge of Lean Project Management?

☐ Low ☐ Fair ☐ Advanced

Section 2: Lean Project Management in Construction Projects
Please indicate your level of agreement with the following statements based on your experience in your organisation.

10. Lean Project Management in Design

Lean Project Management in Design	**Strongly Agree**	**Agree**	**Disagree**	**Stongly disagree**
Leads to better technological efficiency				
Solves potential constructability problems				
Reduces project development time and cost				
Assures supervised quality control procedures				
Aids effective communication among teams				
Eliminates waste and non-value adding activities				

11. Lean Project Management in Construction

Lean in Construction Project Management	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Improves safety and environmental issues				
Reduces lead-time, cost and throughput				
Helps to identify constraint within construction				
Focuses on value than cost.				
Optimises resource delivery schedules				
Aids reduction in on-site transportation				
Results in standardisation of work practices				

12. Lean Project Management Implementation in your organisation

Lean Project Management Implementation	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Increased awarness				
Is similar to the traditional practices				
Has improved competitiveness and market share				
Motivates employees and shapes their behaviour.				
Has complemented marketing effort				
Innovates sustainable competitive advantage				
Is promoted by integration of supply chain				
Enables construction performance initiatives				

13. Link between Lean Project Management and Construction Performance

Link between Lean and Construction Performance	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
The concept of both is very closely linked				
Lean project management is similar to the traditional practices				
Lean project management leads towards construction performance initiatives				
Both eliminate material waste in construction				
Lean project management enhances construction performance				

14. Barriers to Lean Project Management Implementation

Barriers to Lean project Management	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Lack of management commitment				
Long implementation period				
Lack of proper training				
Lack of adequate skills and knowledge				
Lack of application of the fundamental techniques				
Gaps in standards and approaches				
Fragmented nature of industry				
Cultural barriers				
Lack of implementation understanding and concepts				
Resistance to change				
Government bureaucracy and instability				
Long lists of supply chain and lack of trust				

15. Success Factors of Lean Project Management

Barriers to Lean project Management	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**
Management commitment				
Good working environment				
Customer focus and integration				

System and process change management				
Regular training of workforce				
Effective planning				
Integration of team and end to end supply chain				
Adoption of a continuous improvement culture				
Benchmarking of suppliers against each other				
Communication and coordination between parties				
Review of performance/progress towards targets				
Wide adoption of lean concepts				
Understanding of lean benefits in construction project management				

16. Please indicate the level of importance of Lean Tools/Techniques on construction projects you have undertaken.

Tools/Techniques	**Very Importance**	**Important**	**Slightly Important**	**Not important**
Value Stream Mapping				
Kaizen				
A3 Thinking				
Work standardisation				
Six Sigma				
Error Proofing				
Workplace Organisation (5S)				
Visual Management				
Last Planner				
Concurrent Engineering Discrete Event Simulation				
Process Mapping				
Total Quality Management				
Just-In-Time				
Value Analysis				
Daily huddle meetins				
Other (Please Specify)………………………….				

17. How important are the benefits of Lean project management in terms of its level of achievement in your organisation?

Benefits of Lean Project Management	Very Importance	Important	Slightly Important	Not important
Improved corporate image				
Improvement in innovation				
Increased competitive advantage				
Reduced cost, lead-time and throughput				
Improved process flow				
Increased compliance with customers expectations				
Improvement of environmental quality				
Increased employee morale, and commitment				
Reduction in material usage				
Reduction in energy consumption				
Reduction in waste				
Reduction in water usage				
Increased productivity				
Improvement in Health and Safety				
Reduction in workforce				
Increased staff motivation in decision making				

18. Is Lean project management linked to your business strategy?
☐ Yes ☐ No IF No GO TO QUESTION 20

19. Please indicate what aspect
☐ Initiation ☐ Planning ☐ Execution ☐ Control

☐ Others (Please specify) …………………

20. Indicate your level of satisfaction with the implementation of Lean project management in your organisation
☐ Highly Satisfied ☐ Satisfied ☐ Dissatisfied ☐ Very satisfied
☐ Not applicable

21. Kindly supply any additional input/information you consider relevant to the questionnaire
…………………………………………….......................

22. Would you like a copy of the finding? ☐ Yes ☐ No

23. If Yes, please supply your email...

11.3 Appendix III: Interview Questions

1. Tell me a bit about your job - your roles and responsibilities?
2. What are the operational challenges your company has been dealing with?
3. What are the issues that are affecting your company's operational performance?
4. How often do projects in your company go over-time or over-budget?
5. What do you know about Lean construction? Is it transferable to Saudi firms?
6. How could Lean construction practices help deal with time and cost overruns?
7. How effective are traditional project management practices, tools and techniques in terms of dealing with the challenge of time and cost overruns in particular? What are their drawbacks in terms of dealing with contemporary construction challenges?
8. What project planning and control methods do you use to plan construction activities and control your company's operational capacity? What other methods besides CPM (critical path method) do usually use for planning and control of activities?
9. Who usually gets involved in the development of project plans and schedules?
10. What are the things or issues that cause time and cost overruns in your company?
11. Do you think your company is doing enough to optimise its planning and control?
12. How often project schedules were revised or modified by project planners?
13. How do you think your company should improve its planning performance?
14. What do you think about Lean construction's tools and techniques? Do they add any real value to your company's pursuit of optimal operational performance? What are their pros and cons in the context of your organisation?
15. What are the factors or contributors that encouraged your company to adopt the tools and techniques of Lean construction? Do managers actually support the adoption and use of modern project management tools and practices like Lean Construction's?
16. What are the benefits that your company has gained from the implementation of pro-Lean tools, techniques and practices? What do you think of Lean tools like Heijunka (Level Scheduling); Kanban (Workflow Management); LPS; 5S; and Kaizen.
17. What are the factors which have enabled or facilitated the implementation of pro-Lean tools, techniques and systems in your organisation? Do workers and managers have favourable attitudes toward the adoption of pro-Lean initiatives? Do you think the human and behavioural factors play an important role? How about other hard factors like the management systems and structures? Do you think the use of consultants is important and helps with the implementation?

18. What are the factors which have hindered or obstructed the implementation of Lean construction tools, techniques and systems in your company?
19. Do you think the cost of implementation of pro-Lean initiatives a major barrier? How about the investment commitment required for Lean adoption, is it a major barrier?
20. What do you think your company should do to minimise the barriers and maximise the facilitators and enablers of pro-Lean initiatives?
21. Would you like to add anything else?
22. Do you have any questions for me?

11.4 Appendix IV: Sample Interview Transcript

Interview Transcript for Participant CM-01

1. Tell me a bit about your job - your roles and responsibilities?

I manage a big team of designers, architects, engineers, construction workers, and others. I am the one who is responsible for what goes on near the construction site. I communicate and liaison with different teams and departments to make sure that the construction activities are completed at the right time and handover as soon as possible. I lead the team and I ensure that input is made by the relevant departments and persons at the different phases of construction projects. I oversee almost everything from the deployment of workers to the development of construction plans and schedules.

2. What are the operational challenges your company has been dealing with?

Ah! There are so many challenges in this industry and in this company. Where should I start? I think like in all other construction companies, we have problems with productivity and also with accurate estimation of how long it will take to complete a project and also how much it will cost us to construct the different parts of the project. These challenges are more common in larger projects. I mean the larger the project, the more challenging it is to produce accurate time plan and construction schedules. You know we work in an uncertain environment and things change all the time. We don't know what's going to happen tomorrow for certain, but we try to stick to our original plans and timelines as much as we can. We use technology to help us manage these challenges, but they are not enough. In this industry, we got used to having our plans altered and modified all the time. It is just the way it is.

3. What are the issues that are affecting your company's operational performance?

In what way do you mean? Do you mean the things that obstruct our operations? There are numerous things that impact on our operations. There is the issue of complexity and the issue of severe weather events and the things related to availability of resources especially cash. In many cases, there is not much we can do to avoid disruptions to our operations. We do work very hard to improve our performance, but it is not always possible to get where we want due to so many factors like resource constraints, system inefficiencies and the way things here are organised and structured in terms of processes and procedures. So many issues stand in our way, so no matter how hard we work, it is impossible to have a perfect system.

4. How often do projects in your company go over-time or over-budget?

Haha! I think always. As I mentioned earlier; we work in an uncertain and complex place so you should understand that going over time and budget is normal in construction.

5. What do you know about Lean construction? Is it transferable to Saudi firms?

I have general knowledge of its different parts. I attended several workshops and numerous roundtables on the subject. I know that Lean construction is all about improving the way we manage activities by making them Leaner by overcoming all sources of inefficiencies. I like it a lot because it encourages you to be more productive and more systematic in managing all aspects of construction like the people, the way machines are used, and how different things should be deployed and managed. To me, Lean is mainly concerned with applying modern techniques to achieve efficient and effective building and construction plans on time and minimal cost. To answer your second question; Yes, I personally think that Lean construction is applicable to the Saudi construction firms. I strongly support it. It is great!

6. How could Lean construction practices help deal with time and cost overruns?

As I said, Lean improves the way we manage things. That's how it helps reduce the problems of time and cost overruns. It provides us with better management practices and helps us to find ways to solve problems by focusing on their root causes.

7. How effective are traditional project management practices, tools and techniques in terms of dealing with the challenge of time and cost overruns in particular? What are their drawbacks in terms of dealing with contemporary construction challenges?

They are good. I don't see anything with them. They do the job we want them to do. Perhaps they are not as effective as modern project management practices, but sometimes simple is good. You know, we cannot be obsessed with the problem of delays. We have to use what works best for us regardless of whether it is old or new.

8. What project planning and control methods do you use to plan construction activities and control your company's operational capacity? What other methods besides CPM (critical path method) do usually use for planning and control of activities?

We use different tools and methods for planning. Like you probably know, we use the critical path method. We use a specialist programme for that. It helps us focus on the activities which matter the most. Ah! We also use normal Excel sheets to divide activities and assign activities and responsibilities to different persons and teams.

9. Who usually gets involved in the development of project plans and schedules?

So many people get involved in the development of project plans and schedules. This includes the project managers, the construction managers, the site managers, the contractors, the consultants and anyone who can contribute to the development of accurate and realistic plans and time schedules.

10. What are the things or issues that cause time and cost overruns in your company?

Where do I start? There are so many things which cause delay. You are probably aware that failure to plan well and have accurate time schedules is a common problem. Also, having a very complex design or a design that's too complex or unrealistic causes significant delays. If the design is simple, the construction process is usually straightforward, but you know some designers try to be creative and we end up with many problems to troubleshoot. Contractors' failures and absence of vital raw materials also cause trouble. Sometimes simple issues like failing to make a payment on time and place an order for raw materials in time leads to issues and delays construction for several days. Frankly, there are too many possible causes of delay in this industry. We can only manage some of them.

11. Do you think your company is doing enough to optimise its planning and control?

Yes of course. We do it a lot better than so many other companies.

12. How often project schedules were revised or modified by project planners?

It really depends on how big the project is. The bigger the project, the more frequently we have to sit down and modify the initial project plans. Like I said before, we work in uncertain environment. Things change a lot and change rapidly, so we of course have to adapt. We can't just stick to the original plan - that's impractical. I would be lying to you if I say that I have ever managed a construction project without revising or modifying its original schedules.

13. How do you think your company should improve its planning performance?

There are too many things which should be done to improve planning. I would not finish talking if I start listing them here. The main issue and the biggest problem we often encounter is that we don't always get enough time to get our heads to understand a project's scope and we are often rushed to provide rough plans without considering all the factors and issues which could cause delay or significant disruptions. To be honest, even when we get sufficient time, our plans never turn out to be perfect. There are always differences between what we plan and what actually happens on the ground later on. I personally think if we get sufficient time, we can attend to some of the root causes of common planning problems which should help us to improve our planning performance and enable us to develop more accurate plans.

14. What do you think about Lean construction's tools and techniques? Do they add any real value to your company's pursuit of optimal operational performance? What are their pros and cons in the context of your organisation?

I think Lean construction is a good management system. Its tools and techniques are useful in a wide range of areas. They help to improve management procedures, they allow us to explore new ways of optimising our efficiency and also increasing productivity. They are also very good in terms of helping us reduce unnecessary cost. Frankly optimal performance in this industry can't be easily achieved. It will take many systems, many years and significant commitments in cash and resources. There is a long road to perfection.

15. What are the factors or contributors that encouraged your company to adopt the tools and techniques of Lean construction? Do managers actually support the adoption and use of modern project management tools and practices like Lean Construction's?

Like any other system, the promised benefits are what encourage senior management to even consider or think about the use of Lean systems. We of course like to embrace industrial best practices whenever possible and like to stay ahead of others. So you can say that our position in the industry and our design to improve efficiency, productivity, effectiveness and so on are what encouraged us to consider Lean. The managers - mostly support Lean I think. I do not think many managers have a problem with the adoption of new practices especially if their adoption is pushed from the very top of the company.

16. What are the benefits that your company has gained from the implementation of pro-Lean tools, techniques and practices? What do you think of Lean tools like Heijunka (Level Scheduling); Kanban (Workflow Management); LPS; 5S; and Kaizen.

There are many benefits that we get from being Lean. The essence of Lean is efficiency. We get to improve our efficiency, our productivity, our quality and our management practices' effectiveness. Lean tools also help with optimisation of operations, with closer relationships with contractors and our clients. They also help with planning and with forecasting. I think Lean is a very powerful system of management. About the second part of your question, what did you mean by Heijunka? I don't think I have come across it before.

Ah Okay! I understand you now. As you probably know, not all of Lean's tools apply to our company or even to our industry. We have to be selective in terms of which tools are beneficial to our firm and which aren't. I don't think Heijunka would help me with my job.

It sounds like it is more relevant to manufacturers than to us. Yes we want to reduce our lead time and complete projects on time, but Heijunka seems concerned with production lead-time which is not that useful to us. So we basically use the systems and tools that are applicable to our operations and which are practical in their construction management approach.

What are the other tools you mentioned, again?

Ah! Yes! These are good tools. Generally we are very interested in Kaizen and other tools that can help us save cost, reduce time, boost efficiency and improve our quality. I personally like Kaizen. I like its ideas and I like what it's trying to do. We use it to some extent to find solutions to our problems and to prevent problems from happening again in the future.

17. What are the factors which have enabled or facilitated the implementation of pro-Lean tools, techniques and systems in your organisation? Do workers and managers have favourable attitudes toward the adoption of pro-Lean initiatives? Do you think the human and behavioural factors play an important role? How about other hard factors like the management systems and structures? Do you think the use of consultants is important and helps with the implementation?

Erm! Where do I start? The enabling factors are so many. I will just list some of them for you like; sufficient resources, cash, training, experience, expertise, knowledge, consultants, inner drive, good management systems, contractors' support, pressure from clients, and some many other factors which force us and help us to adopt Leaner construction.

Yes! I think in general terms both the workers and managers like Lean and all of its ideas.

Yes of course! Behaviour is everything. Behavioural factors are extremely important because you can't force people to do things they do not like otherwise they wouldn't do it right. You need to encourage them to behave in ways that support the Lean practices. You know I think if the workers don't like Lean or its tools, it will be impossible to implement it in here.

Yes, Yes! The hard factors like the other factors. They also play a very important part in the implementation of Lean. Like I said before, you need good management systems to support a new Lean practice and managerial structures are also important.

Without a doubt! You didn't even need to ask. Consultants are very important because they are more knowledgeable about Lean and its tools than us. How do you expect us to adopt a Lean practice without receiving the guidance and advice from the right consultants?

18. What are the factors which have hindered or obstructed the implementation of Lean construction tools, techniques and systems in your company?

The opposite is true in the case of barriers. Think of it this way; without workers' and managers' willingness, without training and without the use of consultants, it is going to be very difficult to implement a new Lean tool successfully. Also, without good management system, process and procedures and without having the right organisational culture, there is a very good chance that the new tool would fail. More importantly, there needs to be so much pressure from those at the top for things to be implemented and practiced well. The higher the pressure, the more seriously implementation efforts are taken by line managers and workers.

19. Do you think the cost of implementation of pro-Lean initiatives a major barrier? How about the investment commitment required for Lean adoption, is it a major barrier?

It depends really. If the system or tool that we want to implement is worth the case, we often go ahead and implement it and we don't worry so much about the size investment. However, if the tool or system is just an extra, the money could become an issue. If its implementation is not too costly, we will go ahead and adopt it to improve our performance, but if it costs a lot to implement or to practice, then we would not bother at all. Do you understand me?

20. What do you think your company should do to minimise the barriers and maximise the facilitators and enablers of pro-Lean initiatives?

I am not quite sure, but I think we need to be forward-thinking. Our senior managers need to abandon short-termism and consider Lean and its tools as a long-term investment.

21. Would you like to add anything else?

No, I think we covered everything.

22. Do you have any questions for me?

No, I don't think I have any questions at the moment.

11.5 Appendix V (Correspondences with BCC)

1) The – Validation of the list of project's steps timing and process mapping of Construction Activities Procedure as seen in figure 5-4 in the main body of this thesis. (See email 1 below).

9 stories building

16

Othman Khojah <okhojah@bhc.sa>
Thu 17/01/2019 20:52
To: Mohammed Alhalafi

List of Project's Steps timing ...
71 KB

Model 15_01_2019.docx
102 KB

2 attachments (172 KB) Download all Save all to OneDrive - De Montfort University

Dear Mohammed,

I had a look at the model you sent to me regarding the 9 stories building . I believe that is a realistic flow chart of such constructions and I have comments and additional inputs.

I also attached the activity timing distributions list for such constructions. Please find the attachments.

If you need further information then please let me know.

Thanks

Best Regards

Othman Khojah
HR Manager

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7630 Abdullah Al Khurayji
Jeddah 23433 – P.O.2997, KSA

11.6 Appendix VI: SIMIO Simulation Screenshots

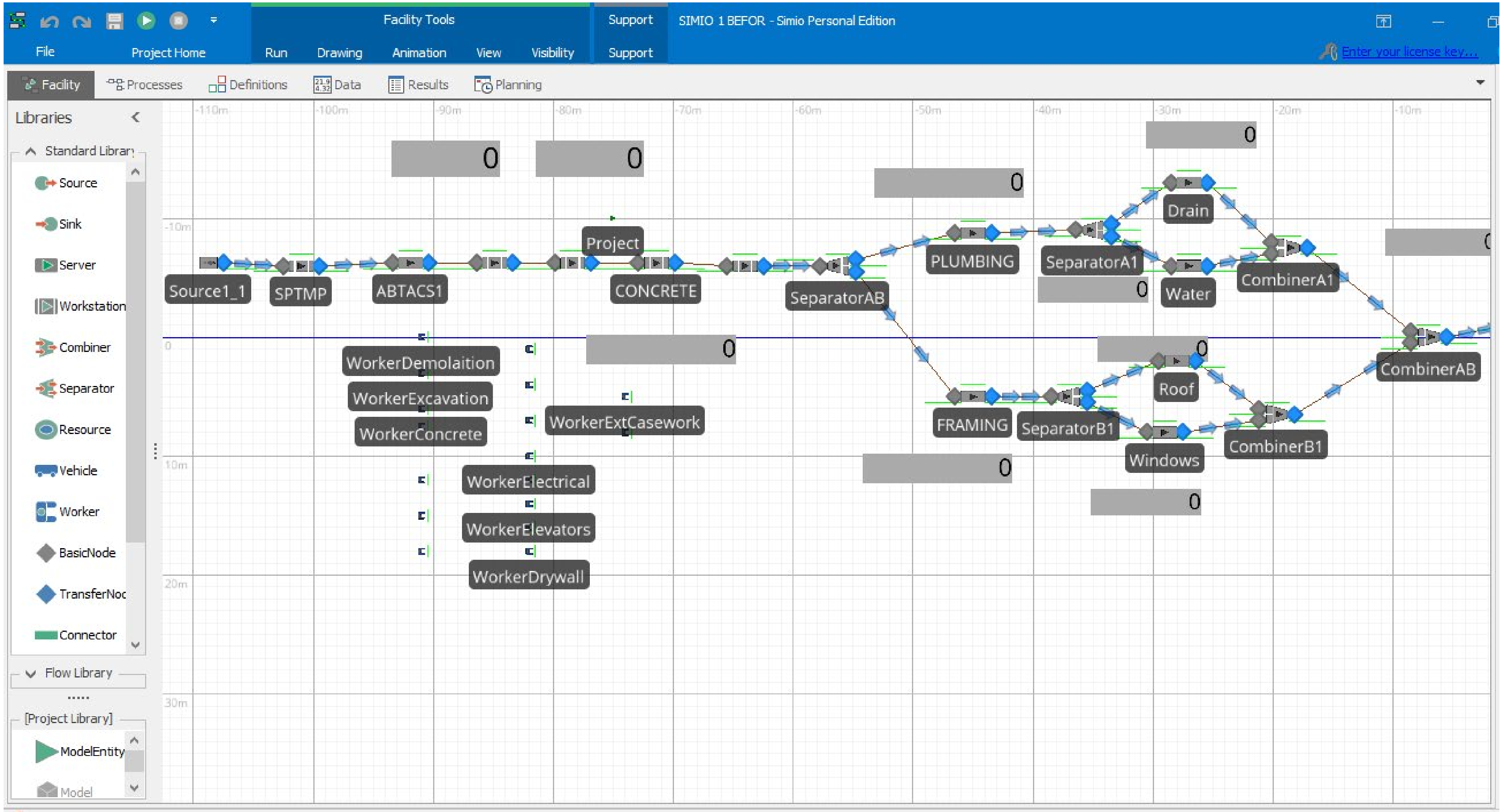


Figure 1: Simio Process Map

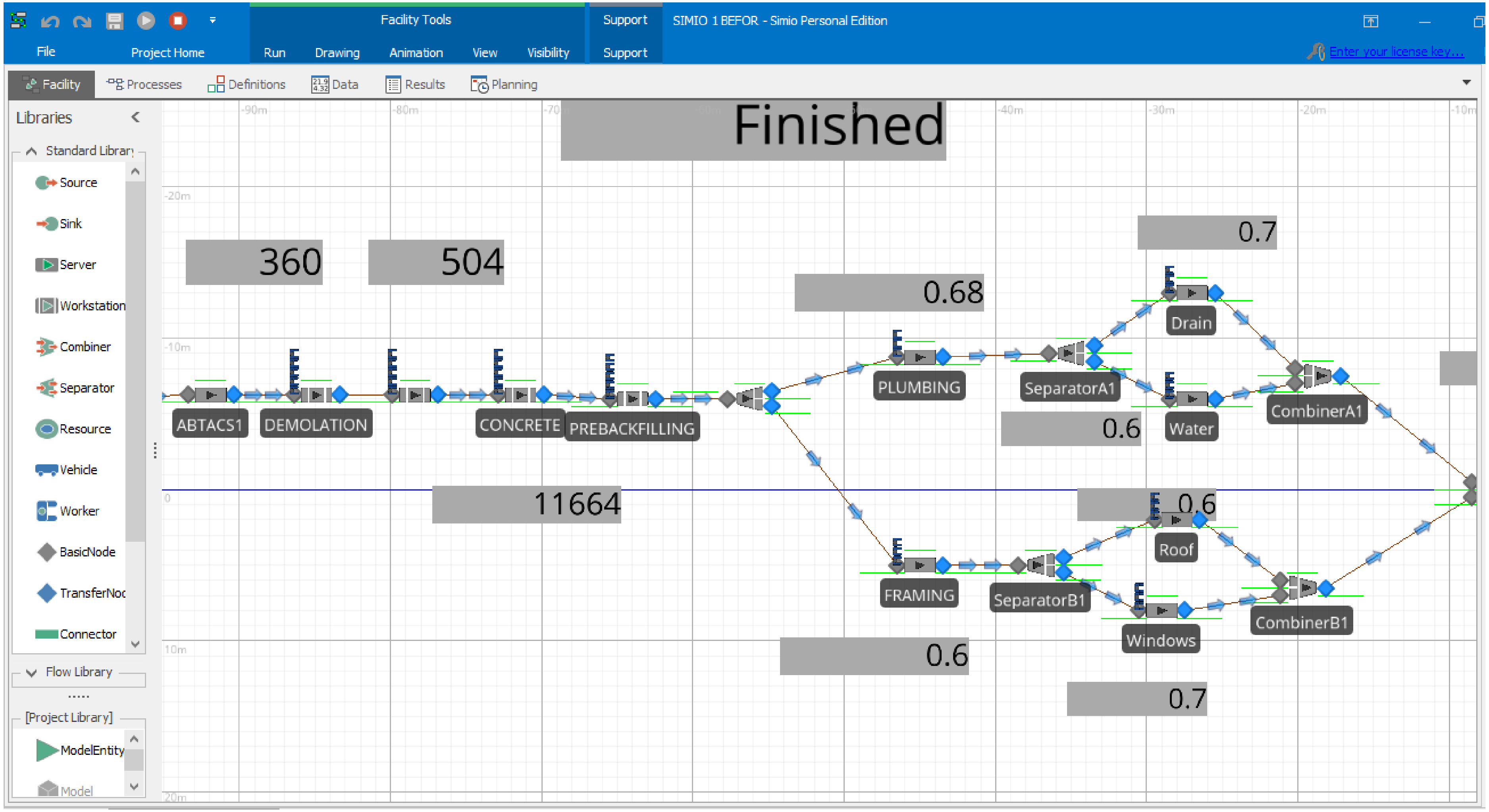
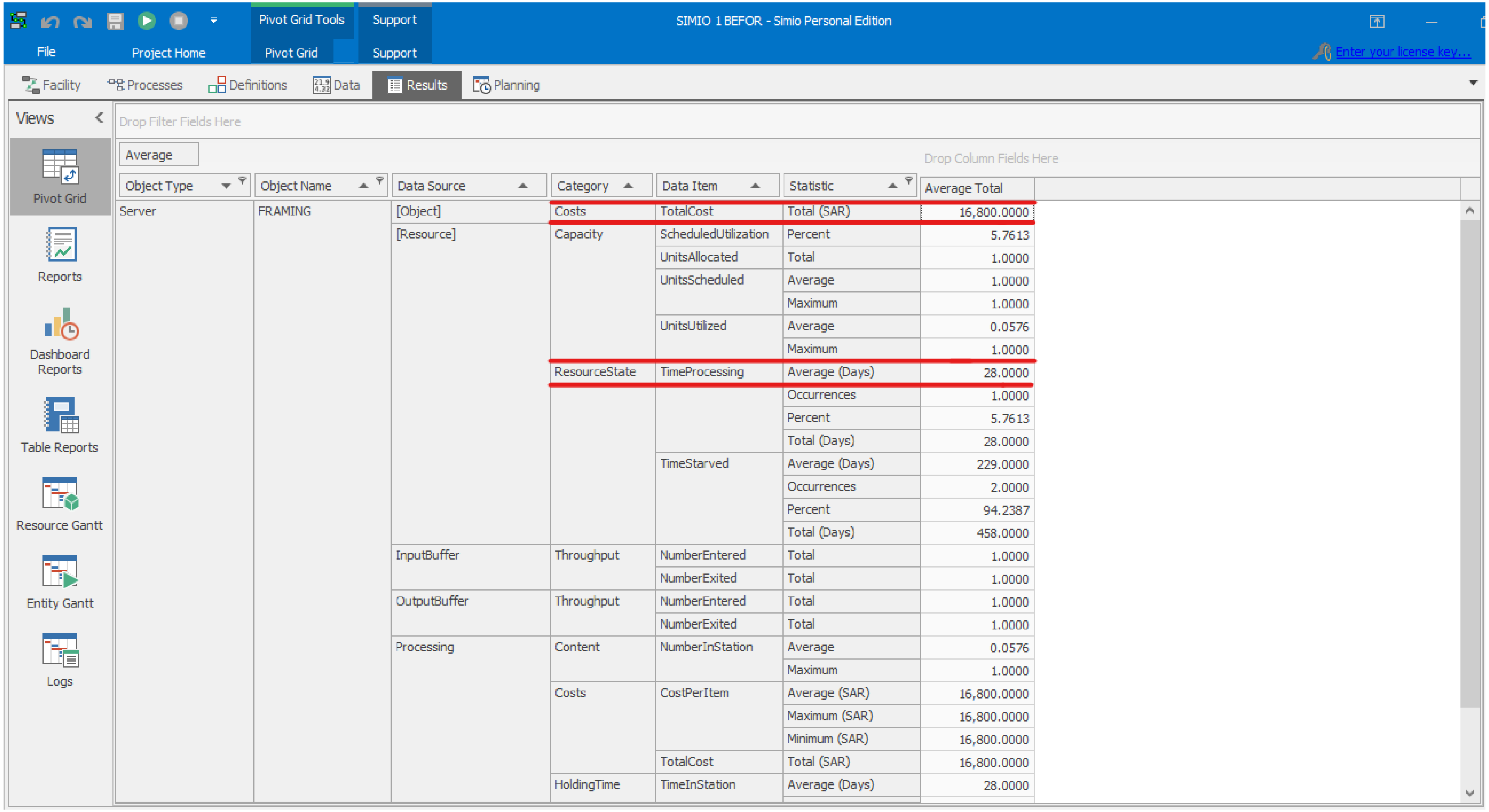


Figure 2: Pre-Kanban Simio Process Outputs



Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
Server	FRAMING	[Object]	Costs	TotalCost	Total (SAR)	16,800.0000
		[Resource]	Capacity	ScheduledUtilization	Percent	5.7613
				UnitsAllocated	Total	1.0000
				UnitsScheduled	Average	1.0000
					Maximum	1.0000
				UnitsUtilized	Average	0.0576
					Maximum	1.0000
			ResourceState	TimeProcessing	Average (Days)	28.0000
					Occurrences	1.0000
					Percent	5.7613
					Total (Days)	28.0000
				TimeStarved	Average (Days)	229.0000
					Occurrences	2.0000
					Percent	94.2387
					Total (Days)	458.0000
		InputBuffer	Throughput	NumberEntered	Total	1.0000
				NumberExited	Total	1.0000
		OutputBuffer	Throughput	NumberEntered	Total	1.0000
				NumberExited	Total	1.0000
		Processing	Content	NumberInStation	Average	0.0576
					Maximum	1.0000
			Costs	CostPerItem	Average (SAR)	16,800.0000
					Maximum (SAR)	16,800.0000
					Minimum (SAR)	16,800.0000
				TotalCost	Total (SAR)	16,800.0000
			HoldingTime	TimeInStation	Average (Days)	28.0000

Figure 3: Pre-Kanban Cost and Lead Time for Framing Activity

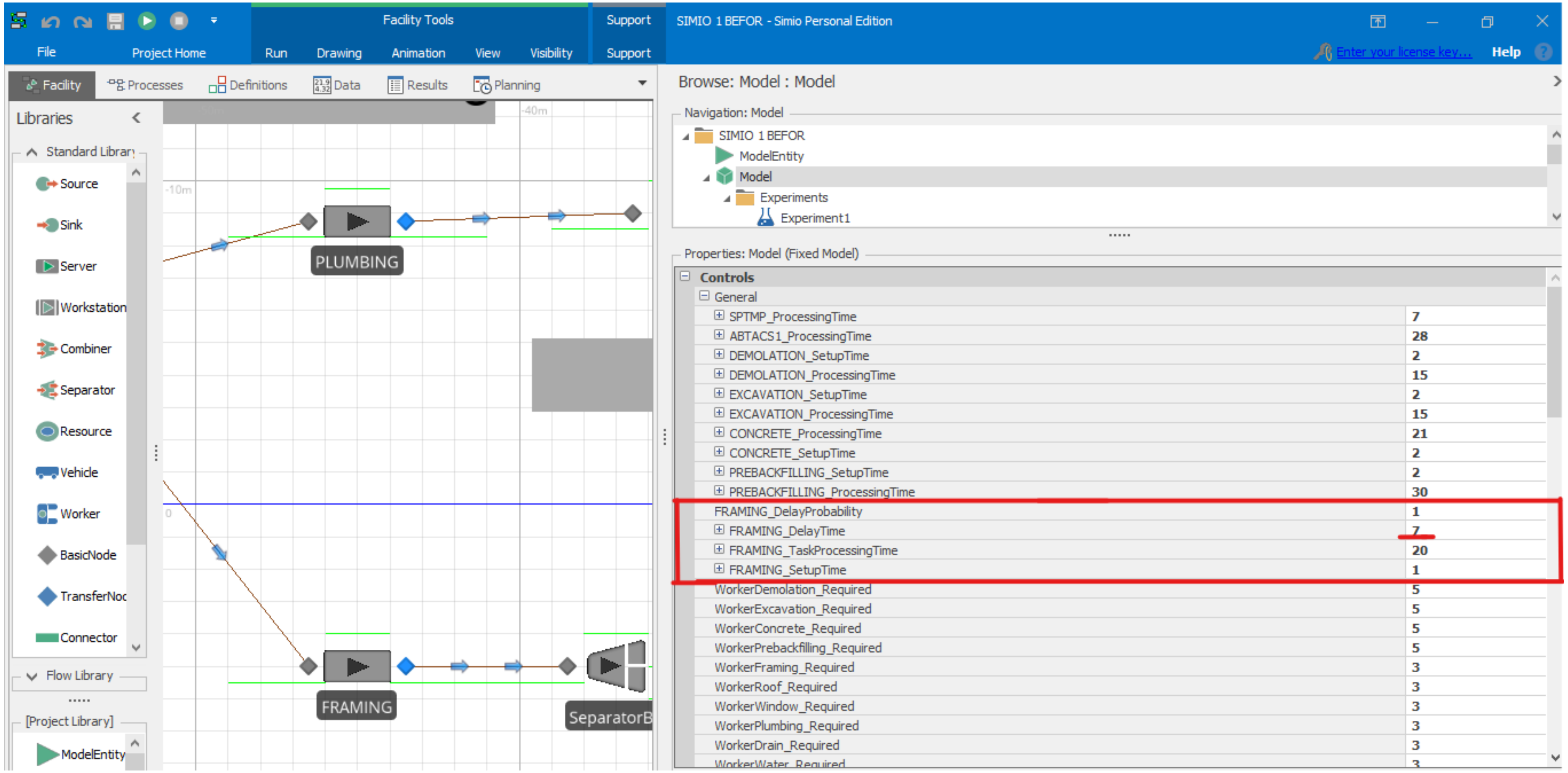


Figure 4: Pre-Kanban Delay Estimates for Framing Activity

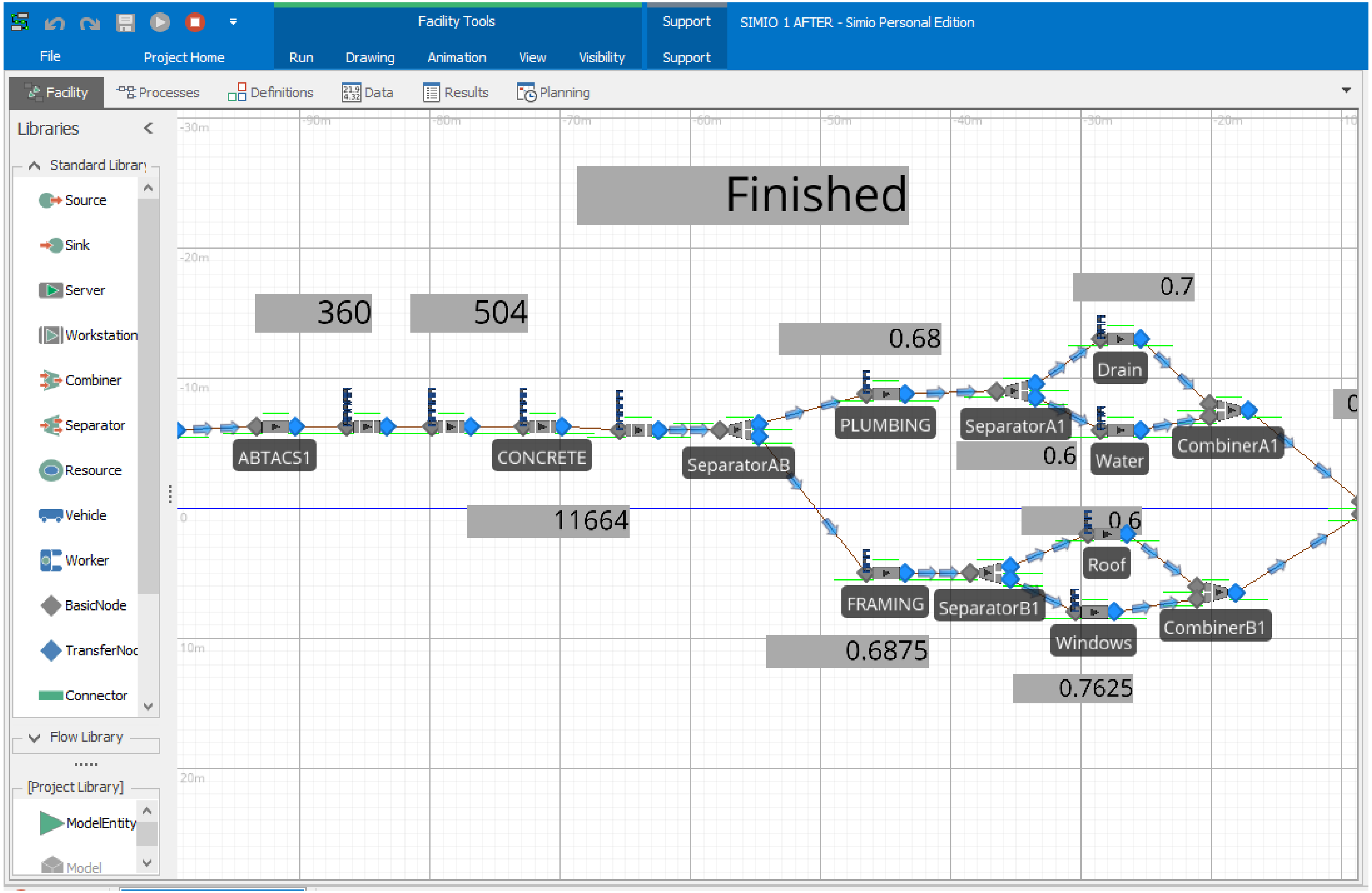
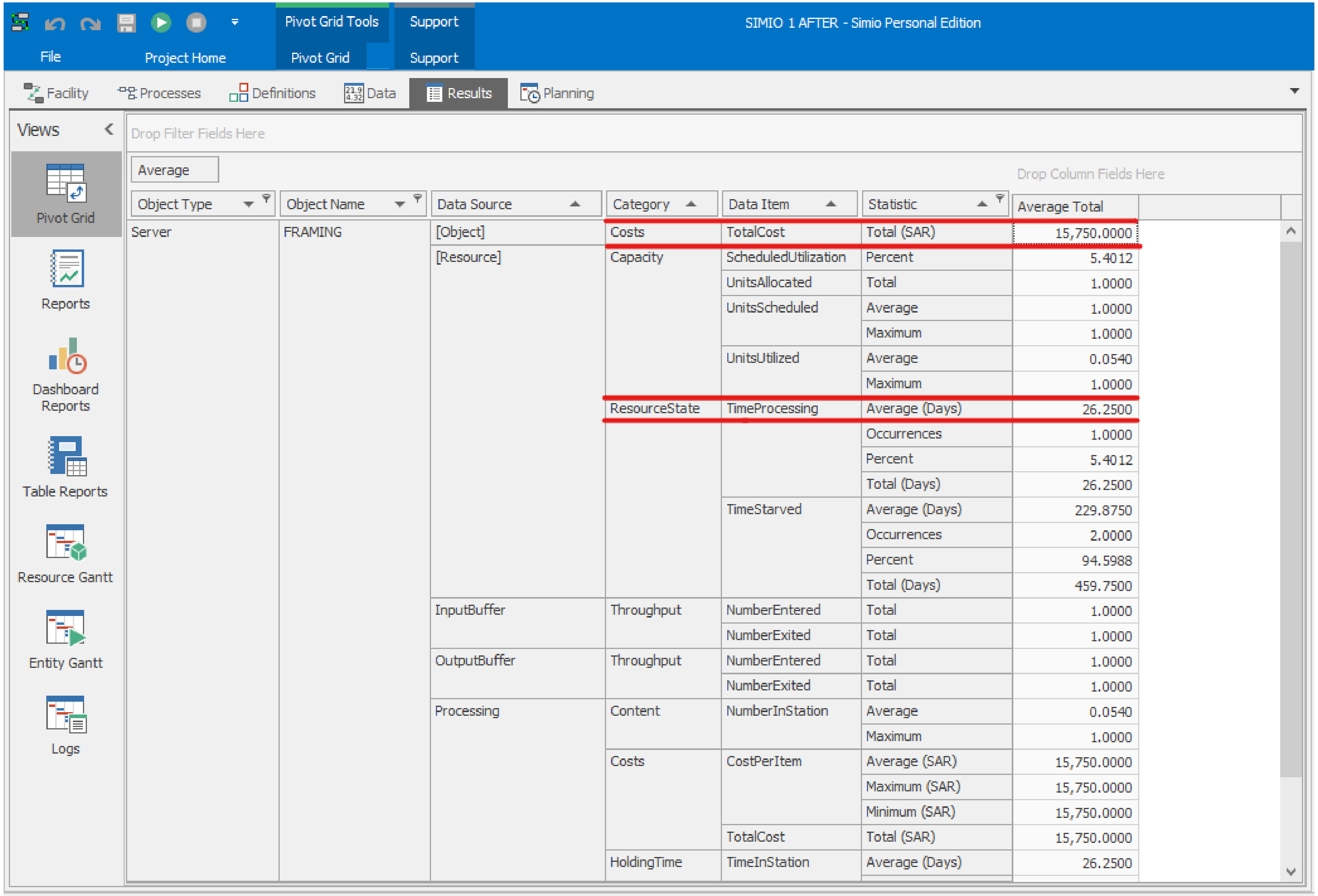


Figure 5: Post-Kanban Adoption Simio Process Outputs



Object Type	Object Name	Data Source	Category	Data Item	Statistic	Average Total
Server	FRAMING	[Object]	Costs	TotalCost	Total (SAR)	15,750.0000
		[Resource]	Capacity	ScheduledUtilization	Percent	5.4012
				UnitsAllocated	Total	1.0000
				UnitsScheduled	Average	1.0000
					Maximum	1.0000
				UnitsUtilized	Average	0.0540
					Maximum	1.0000
			ResourceState	TimeProcessing	Average (Days)	26.2500
					Occurrences	1.0000
					Percent	5.4012
					Total (Days)	26.2500
				TimeStarved	Average (Days)	229.8750
					Occurrences	2.0000
					Percent	94.5988
					Total (Days)	459.7500
		InputBuffer	Throughput	NumberEntered	Total	1.0000
				NumberExited	Total	1.0000
		OutputBuffer	Throughput	NumberEntered	Total	1.0000
				NumberExited	Total	1.0000
		Processing	Content	NumberInStation	Average	0.0540
					Maximum	1.0000
			Costs	CostPerItem	Average (SAR)	15,750.0000
					Maximum (SAR)	15,750.0000
					Minimum (SAR)	15,750.0000
				TotalCost	Total (SAR)	15,750.0000
			HoldingTime	TimeInStation	Average (Days)	26.2500

Figure 6: Post-Kanban Adoption Cost and Lead Time for Framing Activity

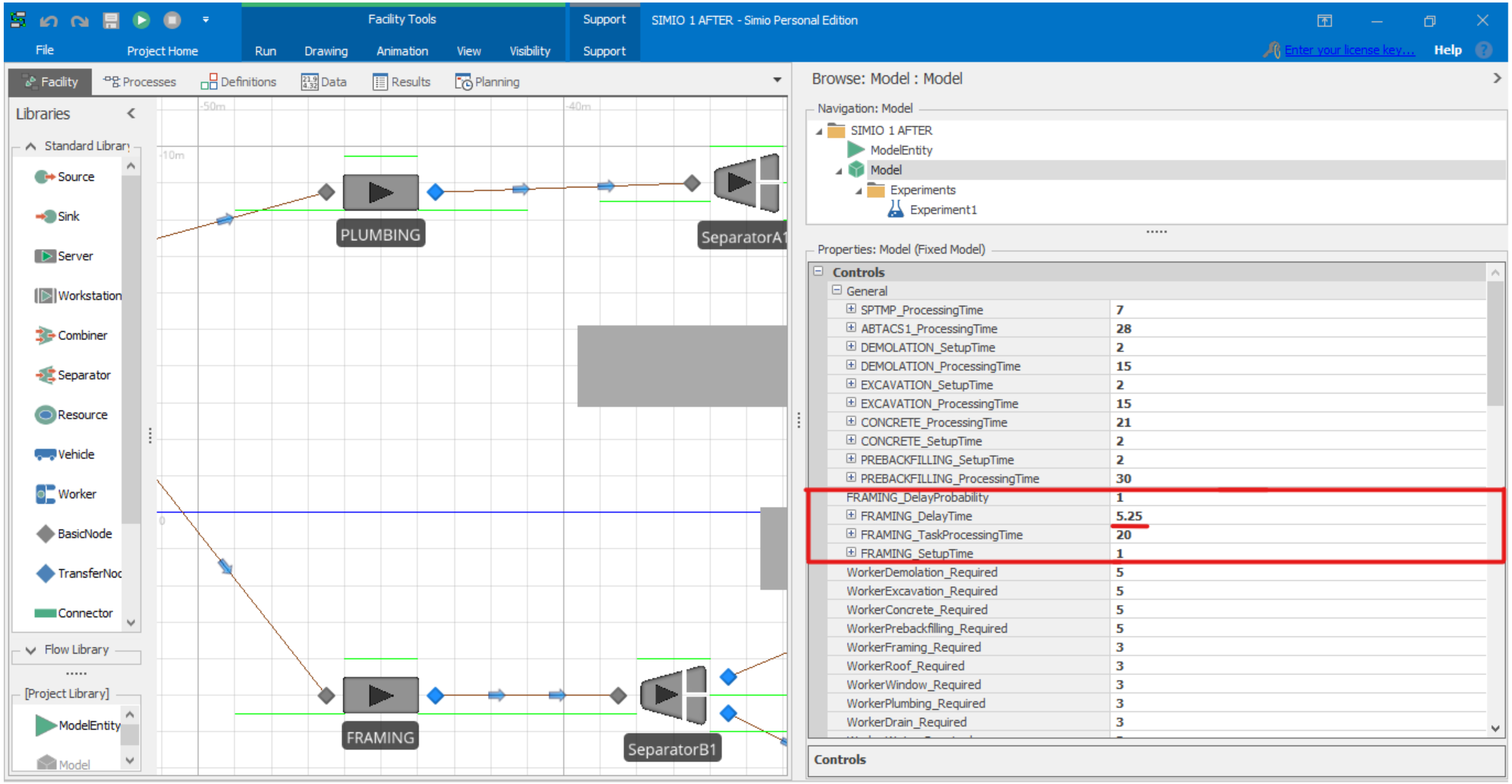


Figure 7: Post-Kanban Adoption Delay Estimates for Framing Activity

11.7 Appendix VII: SIMIO Simulation Tables – Scenarios

Windows Activity			
	BEFORE	AFTER	
Number of Experiments	Actual Time (Days)	Actual Time (Days)	Percentage of Improvement
1	26	24.75	5%
2	42	39.5	6%
3	58	54.25	6%
4	36	32.25	10%
5	37	35.75	3%
6	53	50.5	5%
7	31	28.5	8%
8	47	43.25	8%
9	48	46.75	3%
10	48	46.75	3%
11	31	28.5	8%
12	47	43.25	8%
13	58	54.25	6%
14	26	24.75	5%
15	42	39.5	6%
16	53	50.5	5%
17	36	32.25	10%
18	37	35.75	3%
19	38	36.75	3%
20	51	48.5	5%
21	48	44.25	8%
22	48	44.25	8%
23	46	44.75	3%
24	32	29.5	8%
25	43	40.5	6%

26	56	52.25	7%
27	27	25.75	5%
28	36	34.75	3%
29	52	49.5	5%
30	38	34.25	10%
31	46	42.25	8%
32	47	45.75	3%
33	33	30.5	8%
34	41	38.5	6%
35	57	53.25	7%
36	28	26.75	4%
37	47	45.75	3%
38	33	30.5	8%
39	46	42.25	8%
40	57	53.25	7%
41	28	26.75	4%
42	41	38.5	6%
43	52	49.5	5%
44	38	34.25	10%
45	36	34.75	3%
46	27	25.75	5%
47	43	40.5	6%
48	56	52.25	7%
49	37	33.25	10%
50	38	36.75	3%
51	51	48.5	5%
52	32	29.5	8%
53	48	44.25	8%
54	46	44.75	3%

Table 1: Actual Time Improvements of Windows Activity

Electrical Activity			
	BEFORE	AFTER	
Number of Experiments	Actual Time (Days)	Actual Time (Days)	Percentage of Improvement
1	27	25.32	6%
2	27	25.32	6%
3	27	25.32	6%
4	41	38.75	5%
5	41	38.75	5%
6	41	38.75	5%
7	55	52	5%
8	55	52	5%
9	55	52	5%
10	30	27.75	8%
11	30	27.75	8%
12	30	27.75	8%
13	44	41	7%
14	44	41	7%
15	44	41	7%
16	49	47.32	3%
17	49	47.32	3%
18	49	47.32	3%
19	34	31	9%
20	34	31	9%
21	45	42	7%
22	39	37.32	4%
23	39	37.32	4%
24	39	37.32	4%
25	50	47.75	5%
26	50	47.75	5%
27	50	47.75	5%

28	32	29.75	7%
29	32	29.75	7%
30	32	29.75	7%
31	43	40	7%
32	43	40	7%
33	43	40	7%
34	48	46.32	4%
35	48	46.32	4%
36	48	46.32	4%
37	28	26.32	6%
38	28	26.32	6%
39	28	26.32	6%
40	42	39.75	5%
41	42	39.75	5%
42	42	39.75	5%
43	53	50	6%
44	53	50	6%
45	53	50	6%
46	35	32	9%
47	35	32	9%
48	35	32	9%
49	37	35.32	5%
50	37	35.32	5%
51	37	35.32	5%
52	51	48.75	4%
53	51	48.75	4%
54	51	48.75	4%

Table 2: Actual Time Improvements of Electrical Activity

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Elevators Activity			
	BEFORE	AFTER	
Number of Experiments	Actual Time (Days)	Actual Time (Days)	Percentage of Improvement
1	28	26.25	6%
2	46	42.5	8%
3	64	58.75	8%
4	42	36.75	13%
5	39	37.25	4%
6	57	53.5	6%
7	35	31.5	10%
8	53	47.75	10%
9	50	48.25	4%
10	50	48.25	4%
11	35	31.5	10%
12	53	47.75	10%
13	64	58.75	8%
14	28	26.25	6%
15	46	42.5	8%
16	57	53.5	6%
17	42	36.75	13%
18	39	37.25	4%
19	40	38.25	4%
20	55	51.5	6%
21	43	37.75	12%
22	54	48.75	10%
23	48	46.25	4%
24	36	32.5	10%
25	47	43.5	7%
26	62	56.75	8%
27	29	27.25	6%
28	38	36.25	5%
29	56	52.5	6%
30	44	38.75	12%
31	52	46.75	10%
32	49	47.25	4%
33	37	33.5	9%
34	45	41.5	8%
35	63	57.75	8%
36	30	28.25	6%
37	49	47.25	4%
38	37	33.5	9%

39	52	46.75	10%
40	63	57.75	8%
41	30	28.25	6%
42	45	41.5	8%
43	56	52.5	6%
44	44	38.75	12%
45	38	36.25	5%
46	29	27.25	6%
47	47	43.5	7%
48	62	56.75	8%
49	43	37.75	12%
50	40	38.25	4%
51	55	51.5	6%
52	36	32.5	10%
53	54	48.75	10%
54	48	46.25	4%

Table 3: Actual Time Improvements of Elevators Activity

Drywall Activity			
	BEFORE	AFTER	
Number of Experiments	Actual Time (Days)	Actual Time (Days)	Percentage of Improvement
1	18	16.75	7%
2	18	16.75	7%
3	18	16.75	7%
4	24	22.25	7%
5	24	22.25	7%
6	24	22.25	7%
7	31	28.5	8%
8	31	28.5	8%
9	31	28.5	8%
10	20	18.25	9%
11	20	18.25	9%
12	20	18.25	9%
13	27	24.5	9%
14	27	24.5	9%
15	27	24.5	9%
16	26	24.75	5%
17	26	24.75	5%
18	26	24.75	5%
19	24	21.5	10%
20	24	21.5	10%

21	24	21.5	10%
22	23	21.75	5%
23	23	21.75	5%
24	23	21.75	5%
25	26	24.25	7%
26	26	24.25	7%
27	26	24.25	7%
28	22	20.25	8%
29	22	20.25	8%
30	22	20.25	8%
31	26	23.5	10%
32	26	23.5	10%
33	26	23.5	10%
34	25	23.75	5%
35	25	23.75	5%
36	25	23.75	5%
37	19	17.75	7%
38	19	17.75	7%
39	19	17.75	7%
40	25	23.25	7%
41	25	23.25	7%
42	25	23.25	7%
43	29	26.5	9%
44	29	26.5	9%
45	29	26.5	9%
46	25	22.5	10%
47	25	22.5	10%
48	25	22.5	10%
49	21	19.75	6%
50	21	19.75	6%
51	21	19.75	6%
52	27	25.25	6%
53	27	25.25	6%
54	27	25.25	6%

Table 4: Actual Time Improvements of Drywall Activity

Exterior Casework Activity			
	BEFORE	AFTER	
Number of Experiments	Actual Time (Days)	Actual Time (Days)	Percentage of Improvement
1	23	21.25	8%
2	28	25.5	9%

3	34	30.5	10%
4	28	26.25	6%
5	33	30.5	8%
6	39	35.5	9%
7	34	31.25	8%
8	38	35.5	7%
9	44	40.5	8%
10	36	33.5	7%
11	42	38.5	8%
12	37	35.25	5%
13	25	23.5	6%
14	32	28.5	11%
15	27	25.25	6%
16	31	28.5	8%
17	37	33.5	9%
18	32	30.25	5%
19	33	31.25	5%
20	38	35.5	7%
21	44	40.5	8%
22	23	21.25	8%
23	28	25.5	9%
24	34	30.5	10%
25	28	26.25	6%
26	33	30.5	8%
27	39	35.5	9%
28	30	26.5	12%
29	25	23.25	7%
30	30	27.5	8%
31	35	31.5	10%
32	30	28.25	6%
33	35	32.5	7%
34	39	36.5	6%
35	35	33.25	5%
36	40	37.5	6%
37	35	31.5	10%
38	30	28.25	6%
39	35	32.5	7%
40	40	36.5	9%
41	35	33.25	5%
42	40	37.5	6%
43	30	26.5	12%

44	25	23.25	7%
45	30	27.5	8%
46	31	28.5	8%
47	37	33.5	9%
48	32	30.25	5%
49	36	33.5	7%
50	42	38.5	8%
51	37	35.25	5%
52	26	23.5	10%
53	32	28.5	11%
54	27	25.25	6%

Table 5: Actual Time Improvements of Exterior Casework Activity