DOCTOR OF PHILOSOPHY

The impact of supply chain management on construction projects performance in Jordan

Al-Werikat, Ghaith Khalil Eid

Award date:
2017

Awarding institution:
Coventry University

The Impact of Supply Chain Management on Construction Projects Performance in Jordan

By

Ghaith Al-Werikat

January 2017

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

Acknowledgement

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

"In the name of God, the Most Gracious, the Most Merciful"

“All praise and thanks are only for Allah, the One who, by His blessing and favour, perfected goodness/good works are accomplished”

First, I would like to express my deepest appreciation and thankfulness to my director of studies Dr. Messaoud Saidani and Dr. Abdussalam Shibani for their endless support, help and motivation throughout finalising this research… I have been so honoured to have you.

My Mother… a never-ending song of happiness, unconditional love, support, motivation and wisdom. Without you I would not have been writing this. You had held my hand for a while but my heart forever…

My Dad, Khalil…my great friend and mentor. Thank you for all the care and the endless encouragement. I have been so lucky to have a dad like you...

My brother, Suhaib… you have been nothing but the reason why my heart beats. Thanks for your love, care and jokes. I am so fortunate to have you…

My friends and family… thanks a lot for your care, concern and warm support. You have been always there for me… without you I would have finished this thesis earlier! A special thanks to everyone that helped me throughout my work, much appreciated and god bless…

Sincerely

Ghaith Al-Werikat

Abstract

Construction supply chains encounter a number of problems that can be the result of various disruptions within the construction supply chain flow. The flows within the construction supply chain are as follows: material, labour, equipment, information (client related) and management information flows (main contractor related). This research is debatably one of the first endeavours to quantify the construction supply chain flows impact on construction projects performance, on residential housing construction projects in Jordan in terms of time delays and to what extent it may affect project performance. Jordan differs from other countries in the middle east in terms of its culture, political situation and social fabric. The main aim of this research is to critically analyse the effect supply chain management has on the performance of construction projects. The adopted research methods incorporated preliminary investigation, main survey and simulation scenarios development. The preliminary investigation was conducted through regular site visits to two residential housing projects situated in Amman, Jordan over a two-month period. The main survey was conducted in order to highlight the problems faced by the construction industry regarding supply chain flows. The data gathered from the main survey were used in developing the simulation scenarios. The simulation scenarios were developed on a Critical Path Method (CPM) network of a residential housing project using Microsoft project 2007 and the main survey data were incorporated by applying the highest pessimistic value of each flow element to the related activity's duration. The results revealed that problems in the information flow within the main contractor's company (management flow) caused the greatest impact on the project with a delay of 302 days. Labour flow ranked second with 125 days, followed by material flow with 69 days, information flow (client related) with 9 days and equipment 3 days. The findings of this research highlighted the status of the construction supply chain in Jordan, quantified the impact of construction supply chain flows on residential housing projects performance in time, provided possible solutions and corrective actions to overcome issues within the construction supply chain and proposed guidelines to integrate supply chain management in the Jordanian construction industry starting with a shift from the traditional contractual framework, then the integration of organisational processes regarding all participants together with long term commitment and trust. The integration would benefit the client and the contractor regarding the overall delivery of the final project but moreover, increased profit margins, decreased aggravation and stress.

Keywords: construction management, supply chain management, risk management, delays, simulation and construction project performance

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List of abbreviations

BPM	Business Process Management
DP	Demand Planning
ERP	Enterprise Resource Planning
JIT	Just in Time
MRP	Material Requirement Planning
QA	Quality Assurance
QC	Quality Control
ROI	Return in Investment
SC	Supply Chain
SCM	Supply Chain Management
VAN	Value Added Network
DFD	Data Flow Diagram
CPM	Critical Path Method
SS	Start to Start
SF	Start to Finish
FS	Finish to Start
FF	Finish to Finish
WBS	Work Breakdown Structure
EDM	Electronic Document Management
DSA	Downstream Strategic Alliance
ADM	Arrow Diagramming Method
CPA	Critical Path Analysis
WIP	Work in Progress
MRP	Manufacturing Resource Planning
MWR	Material Withdrawal Request
BPR	Business Process Reengineering
GDP	Gross Domestic Product
PERT	Program Evaluation Review Technique
GUI	Geographic User Interface
PDM	Precedence Diagramming Method

Chapter 1

Introduction

This chapter provides a general overview of the research.

1.1 Background: This section demonstrates the importance of the research.

1.2 Gap in research: This section reviews current research with regards to supply chain management in the construction industry and highlights the gap in research and justifies the need.

1.3 Aim and objectives: The main purpose of this research is explained in detail in this section.

1.4 Research questions: This section outlines the research questions.

1.5 Research scope: This section defines the limitations within this research and describes the main focus of the research.

1.6 Contribution to knowledge: This section describes the contribution this research is providing to knowledge.

1.7 The structure of the thesis: This section provides a brief overview of the contents of each chapter within the thesis.

1.1 Background

The construction industry is considered among the oldest industries in the world, deemed advantageous by some people, whilst others believe the industry is problematic and indeed a sophisticated process which is difficult to manage. Most traditional methods are still practised in the construction industry today.

Recent reports in the construction industry highlighted that construction performance continues to have low profit margins and low performance simultaneously (Agapiou et al., 1998, Yeo and Ning, 2002, Cox and Ireland, 2002). Several processes in construction are inadequate and lack efficiencies due to various problems including i.e. Time delays, quality, waste, controllability and budget overrun (Kornelius and Wamelink, 1998, Vrijhoef and Koskela, 2000, Langford and Retik 2012, Ochieng, Price and Moore 2013). Issues within supply chain management in particular, remain a cause for concern and prove to be extremely complicated. Potentially, large numbers of suppliers and sub-contractors may be involved, particularly in large projects. During the many construction stages, any material delivery delays may have a negative impact upon the whole construction work thus, if the activity is classed as critical, the project will be delayed as a consequence. Similarly, should the project delays be caused by work carried out by the sub-contractor, this will in turn have major consequences on other parties as, in most cases, the number of sub-contractors in any given project may reach a thousand for the entire year. According to Scott et al., (2001), a family running a construction business in Wales hired in excess of 3000 sub-contractors and suppliers.

Hence, in order to achieve the best results upon completion of a construction project, careful attention must be given by the managers of activities, when managing the supply chain route. This must be carried out adequately and effectively during the lifecycle of the project. O'Brien and Fischer (1993) highlighted that there is a high possibility of enhancing the construction project productivity by improving the supply chain during the life cycle of the project.

1.2 Gap in research and research problem

According to Kadeforsi (1999) the majority of research on supply chain management was firstly conducted in the manufacturing industry therefore, supply chain management research in general is carried out from this industry's viewpoint. The development process of SCM was carried out in the manufacturing industry, making the application process on that industry more favourable than others, (Rojas, 2014). Moreover, Hurst (2013), claimed that construction firms are not interested towards supply chain management. On the other hand, SCM is considered as a new concern in the construction industry (Greenwood, 2001, Kale and Arditi, 2001). According to Dave and Koskela (2009), there are three reasons that differentiate the construction industry from other industries: site production, temporary organisations and one-of-a-kind projects. Recent researches in supply chain management within the construction industry have focused on the following three elements 1. Contractor - Subcontractor - Supplier relationships, (Kumaraswamy and Matthews 2000), 2. Risks in supply chain management (Greenwood, 2005), 3. Supply chain management client's role (Briscoe et al., 2004), although, thus far, only limited research has been conducted regarding the effect of SCM practice on construction site performance.

1.2.1 Research problem

Previous research adopted a more descriptive technique with a small degree of emphasis on quantitative outcome. Moreover, conducting such a research may aid the development process of the construction industry regarding supply chain management. Which all provides justification and opens an opportunity to conduct the present research and provide quantitative outcomes related to the impact of supply chain management on construction projects performance.

1.3 Aim and objectives

The research aim is to investigate the extent of the impact of supply chain management on overall performance of residential housing projects, with focus on two projects that were carried out in Jordan. Moreover, the objectives of this research are as follows:

1- Critically analyse supply chain management in the manufacturing and construction industry.
2- Critically analyse the impact of supply chain management practice on construction projects performance.
3- Develop simulation scenarios that simulates the influence of SCM practice on the performance of residential housing construction projects in Jordan.
4- Use the simulation scenarios in examining projects performance sensitivity to supply chain management practice and, to what extent it may affect the project.

1.4 Research questions

- What is the current status of supply chain management in manufacturing and construction?
- What are the impacts of construction supply chain on the residential housing projects and the construction industry in general?
- What are the most common delays related to supply chain management and what are their effects on residential housing projects in Jordan?
- What are the effects of supply chain management delays on the projects performance and to what extent it may affect residential housing construction projects performance in Jordan?

1.5 Research scope

The research focus is on supply chain management and construction performance. The study will be at the construction project site level.

1- This research will study project performance in terms of time only.
2- Data collected from the literature review, regular visits, and main survey will be synchronised in the process of simulation scenarios development.

1.6 Contribution to knowledge

1. This research is debatably one of the first attempts to quantify the construction supply chain flows impact on construction projects performance, on residential housing construction projects in Jordan and to what extent it may affect project performance.

2. This research pointed out the impact of each element of the construction supply chain on projects performance separately and all together.

3. This research discusses and proposes guidelines to the process of integrating supply chain management efficiently in the construction industry in Jordan

1.7 The structure of the thesis

The following presents the research structure and a brief outline of the chapters the research is comprised of:

1- Chapter 1 Introduction: this chapter briefly discusses the research and sheds light on the research background, gap, aims and objectives, scope and structure.

2- Chapter 2 Literature review: this chapter discusses supply chain management, its origins, comparisons between supply chain management in the manufacturing industry and the construction industry and other related literature topics.

3- Chapter 3 Research methodology: this chapter discusses the existing research methods in literature and illustrates the adopted methods for this research.

4- Chapter 4 Discussion of preliminary investigation and the main survey: this chapter presents the lessons learnt and the findings from the survey and investigations.

5- Chapter 5 Simulation scenarios development process: this chapter details the process involved in the development of the simulation scenarios, PERT analysis, the validation and verification techniques adopted and the software used.

6- Chapter 6 Results discussion: this chapter discusses the outcome of the simulation process, discussion of all scenarios, a comparison between all results, the implications of the results and supply chain management integration.

7- Chapter 7 Conclusions and recommendations: main outcomes and conclusions of this research are discussed in this chapter also proposes recommendations.

Chapter 2

Literature review

This chapter discusses supply chain management, its background and related topics as follows:

2.1 Supply chain management introduction: this section discusses the supply chain, its origin, definitions, the evolution of supply chain management and related topics.

2.2 Supply chain management and logistics in construction: this section discusses logistics and supply chain management in construction and their differences.

2.3 Construction supply chain characteristics: this section illustrates the characteristics of the construction supply chain.

2.4 Stakeholders and construction supply chain: this section discusses the parties involved in the construction supply chain.

2.5 Construction supply chain problems: this section discusses the problems that supply chain management and the construction industry may encounter.

2.6 Supply chain performance measurement: this section sheds light on possible ways to measure supply chains.

2.7 Comparing supply chain in construction and manufacturing: this section discusses the differences between supply chain management in both the construction industry and manufacturing industry.

2.8 supply chain management integration in the construction industry: this section discusses SCM integration process in the construction industry, barriers and importance.

2.1 Supply chain management

2.1.1 Supply chain definition

A clear definition of supply chain is required in order to understand further discussions and key points regarding this management concept, its importance in general and in project management in particular.

Table 1 illustrates varying definitions proposed by a number of authors.

Authors	Supply chain definition
(La Londe and Masters, 1994)	“a number of companies that forward materials”
(Holmberg, 1997)	“activities performed by a group of organizations in order to satisfy the final customer”
(Lambert et al., 1998)	“the calibration of organisations that takes services or products to the market”
(Handfield and Nicholas, 1999)	“all processes aligned with the transformation and flow from row materials to final products towards the customer”
(Tommelein et al., 2003)	“a collaboration of individuals and companies operating in a chain of interconnecting processes”
(Horch, 2009)	“a package of logistics including material, information and finance organisations”
(Bolstorff and Rosenbaum, 2012)	“a combination of geography, customer and product. Can also include financial reporting and other factors”

Table 1 Definitions of supply chain

According to the previous definitions it could be determined that a supply chain encompasses a network of firms or set of organizations aligned together through the process of transforming raw materials into final products delivered to the end customer.

Moreover, Mentzer et al. (2001) categorised supply chains into three different types based on the level of organizations involved. In addition, the same authors have proposed a framework that focused on the firms cross functional interactions and other relationships developed with other supply chains as figure 1 illustrates.

Figure 1 Model of Supply Chain Management obtained from Mentzer et al. (2001)

The following points shed light on the different types of supply chains based on Mentzer's et al. (2001) work.

1- Basic supply chain: contains a company, direct supplier and direct end-customer all linked by one or more of the upstream or downstream flows of services, products, information and finances.

2- Extended supply chain: this type consists of suppliers of the direct supplier and customers of the final customer all linked by one or more of the upstream or downstream flows of services, products, information and finances.

3- Ultimate supply chain: this is the most complicated type of supply chains and it includes all parties involved in the upstream and downstream flow of information, finance service and product.

2.1.2 Supply chain management definition

The definition of supply chain management has changed overtime and numerous researchers proposed different definitions of that concept. Table 2 provides some examples of the various definitions of supply chain management.

Authors	Supply chain management definition
Bowersox, Closs and Cooper (2002)	Supply chain management consists of firms collaborating to leverage strategic positioning and to improve operating efficiency
Krajewski, Ritzman and Malhotra (2007)	"Supply Chain Management consists of developing a strategy to organize, control and motivate the resources involved in the flow of services and materials within the supply chain."
Bozarth and Handfield (2008)	"Supply Chain Management is the active management of supply chain activities and relationships in order to maximize customer value and achieve a sustainable competitive advantage."
Wisner, Tan and Leong (2012)	"Supply chain management is the integration of trading partners' key business processes from initial raw material extraction to the final or end customer, including all intermediate processing, transportation and storage activities "

Table 2 Definitions of supply chain management.

Having reviewed several authors' definitions and terminologies of supply chain management, Mentzer et al (2001) classified definitions of supply chain management into three categories; SCM as the implementation of management philosophy, SCM as a set of management processes and SCM as a management philosophy. Categories were established according to the way researchers approached SCM.

2.1.3 Supply chain management evolution

As different definitions and terminologies of SCM exist, researchers have traced how these different approaches to SCM have evolved overtime. Rushton et al. (2000) clarified the evolution process of SCM from the logistics and distribution perspective as shown in table 3.

Time periods	Description
1950-1960	Unsystematic distribution systems represented by manufacturers account fleets. There was not enough control between the different distribution activities.
1960-1970	Development of the physical distribution concept and the recognition of the ability to link some physical activities in the distribution process together such as: storage, packaging and transport. This linkage enabled the use of a systematic approach to manage parts of the distribution process and the total cost.
1970-1980	Considered as the most important years in the development process of the distribution process. Distribution was added to the functional management organisation. Huge changes in the distribution structure as retailer's power increased in controlling the distribution process and suppliers and manufacturers power decreased. In addition, large retailers started to develop their own distribution structure to manage the supply process to their stores.
1980-1990	The efficiency and effectiveness of the distribution process improved and long term plans were set to improve quality, reduce cost and storage levels in stores. The use of technology started to become the most reliable factor in the controlling and monitoring process. The need for integrated systems that organise logistics was identified.
Late 80s and early 90s	Organisations started to expand their functions by searching and adding functions that can be integrated. Emerging this with information technology helped in combining physical distribution with materials management (inbound and outbound materials). This combination improved customer service and reduced costs associated with that process.
1990-2000	Further development to include functions that participated in supplying final customers with products, which is also known as supply chain management. Different organisations started to adopt involvement programs with other organisations to supply final customers
2000+	The incremental competition in the market influenced organisations to review their business objectives and to reengineer their systems, including logistics, which is recognised as an important concept that has a positive influence on the business and no longer a costly concept.

Table 3 Evolution of supply chain management from the logistics and distributions perspective (Rushton et al., 2000)

On the other hand, Tan (2001) traced the evolution of SCM from the management of production perspective as can be seen following in table 4.

Time periods	Description
1950-1970	Most firms used to rely on the mass production strategy, with some flexibility in the process, in order to decrease production costs which led manufacturers to focus on unit production price more than unit development. Manufacturers invested hugely in technology, expertise and work in process (WIP). At the time, manufacturers did not realise the importance of strategic and cooperative supplier-buyer partnership, therefore manufacturers considered it risky to share their knowledge and internal strategies with suppliers or customers. In addition, decision makers in manufacturers realised purchasing as a service to production and therefore it was not involved in the production process.
1970-1980	Manufacturing resource planning concept (MRP) was introduced and had a huge impact on new product development, manufacturing cost, quality, delivery lead time and work in process (WIP). Also, new materials management concepts were adopted at that time, in order to improve overall performance in all production processes.
1980-1990	Leading organisations focused on producing flexible designs in order to achieve high quality, lower cost and reliable goods, due to the high world-wide competition at that time. Moreover, manufactures focused more on cycle time and manufacturing efficiency by using just in time (JIT) and other management approaches. In addition, manufacturers began to realise the possible benefits of cooperative and strategic supplier-buyer relationships. The concept of supply chain management materialised as organisations tried strategic partnerships with their first tier suppliers. Professionals in logistics and transportation considered that integration between transportation functions and physical distribution should be adopted as supply chain management or integrated logistics concept.
1990-2000	Organisations focused more on the management of resources to incorporate the logistics function and strategic suppliers in the value chain. Price and quality concerns were highlighted in efficiency of suppliers.

Table 4 Supply chain management evolution from the management of production perspective (Tan, 2001)

Tables 3 and 4 presented different perspectives of SCM evolution. Croom et al (2000) stated that:

> Such a multidisciplinary origin and evolution is reflected in the lack of robust conceptual frameworks for the development of theory on supply chain management. As a consequence, the schemes of interpretation of supply chain management are mostly partial or anecdotal with a relatively poor supply of empirically validated models explaining the scope and form of supply chain management, its costs and its benefits.

The different perspectives regarding the evolution of SCM have contributed significantly to the concept of SCM and the breadth of literature on the subject. During the development stages, many contributions were received regarding SCM from other fields, discussed in detail in the following section.

2.1.4 Bodies of literature development

As mentioned before, researchers had different perspectives of looking at SCM, its evolution and development process. Croom et al (2000) stated that the origins of SCM concept are vague, but SCM development evolved simultaneously with transport and physical distribution development. The same author highlighted the literature of different subjects and the way in which it contributed to SCM such as: organisational behaviour, marketing literature, purchasing literature, network literature and many others. The following points identify the main concerns of some subjects that are related with SCM based on Croom et al (2000) work.

➢ **Strategic management:**

- Strategic supplier segmentation
- Make or buy decisions
- Strategic purchasing
- Supply network design
- Control in supply chain

➢ **Logistics**

- Cross docking
- Forecast information management
- JIT, MRP, waste removal
- Distribution channel management
- Integration of materials and information flows

➢ **Organisational behaviour**

- Human resource management
- Organisational learning
- Organisational structure
- Communication

➢ **Marketing**

- Customer service management
- Relationship marketing
- Internet supply chains

➢ **Relationships/partnerships**

- Supplier development
- Supplier involvement
- Strategic alliance
- Relationship marketing

As can be seen in the previous points, some common overlaps appeared between different subjects. For instance, between relationship/partnership and marketing, relationship marketing is considered as an overlap between those two subjects. This overlap, and many others, show that a specific topic can be analysed and studied from different perspectives and in different subjects. All of these overlaps enriched and supplemented supply chain management as a study field.

On the other hand, the more overlaps between subjects related to supply chain management may enhance it as a field to study. Nevertheless, it might also broaden supply chain management and make its boundaries unclear. Larson and Halldorsson (2004) contributed that unclear supply chain management conceptual boundaries makes it difficult to prepare research programs and educational materials in supply chain management without the need to discuss other fields which interact with SCM namely: purchasing, operation management, marketing and logistics. The next section sheds light on two main fields that are related to supply chain management: purchasing and logistics.

2.1.5 Supply chain management, purchasing and logistics

2.1.5.1 Purchasing

According to Arnold (2001) purchasing is the process of buying. Functions involve obtaining the proper material, in a timely manner, in the correct quantity, from the correct source and indeed at the correct price.

Rushton et al (2010) suggested, purchases can be categorised according to their level of importance. The reasoning behind the categorisation is to make to use the correct amount of effort and time on the most significant purchases of the organisation. Classification of products is necessary in accordance to their importance and indeed annual purchase value. Rushton et al (2010) identified four categories including commodities, critical items, routine purchases and strategic items. Purchases which are routine, generally have low purchase value annually and are not essential to an organisation whereas, strategic items are very critical and have a high annual purchase value to the business.

Categorisation based on the hierarchy of importance can be further categorised, according to the process of buying products. Routine purchases are available both quickly and easily by way of online catalogues which helps to increase speed plus limits the transaction cost. For high annual purchase value commodities, a tendering process is appropriate in order to get the best price. In contrast, critical items have a low purchase value annually and involve a network of regular contracted suppliers as well as having an established supplier selection system. Strategic items are very important to the business, they have high annual purchase value and according to Rushton et al (2014), they should involve strategic alliances with suppliers. The latter recommendation here is not a new one and other writers have discussed the benefits of such strategic alliances for many years.

2.1.5.2 Logistics

Similar to SCM itself, there are a number of different definitions of logistics. According to the Oxford dictionary (2015) 'logistics' is the activity of organising the movement, equipment, and accommodation of troops. The reference to 'troops' here suggests that that term was originally used in a military capacity and has been adopted as a management concept. The Council of Logistics Management (CLM, 2007), defined logistics management as a segment of SCM that controls, plans and implements the forward and reverse flow of goods and storage. Figure 2 next discusses the SCM and logistics from different perspectives.

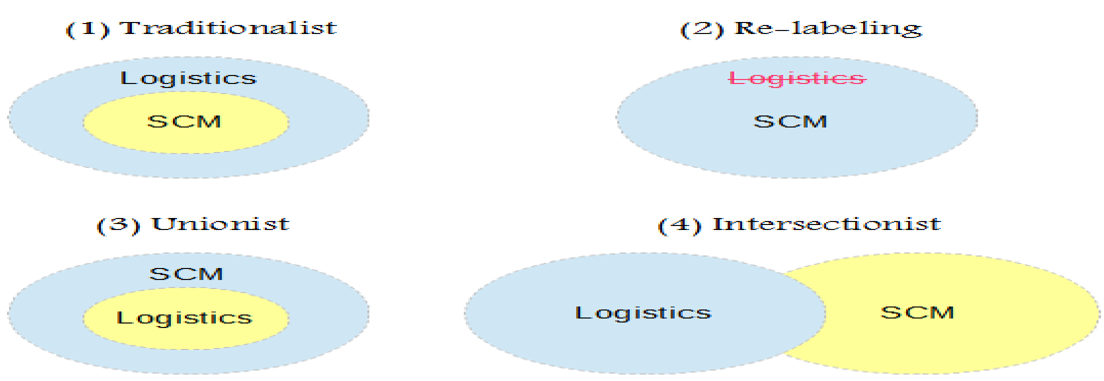

Figure 2 Supply chain management verses logistics from different perspectives adopted from (Larson et al., 2007)

The definition mentioned before by The Council of Logistics Management is very similar to the Unionist view of logistics as outlined by Larson and Halldorsson (2007). Other writers however, do not agree that logistics is necessarily a part of SCM. Hatmoko (2008) used the work of Larson and Halldorsson (2007) when referring to writers who take a reversed traditionalist perspective, in which SCM is actually a part of logistics. These approaches reflect the different perspectives about the relationship between SCM and logistics and they clearly indicate on-going areas of contention in the logistics/ SCM arena.

2.2 Logistic and supply chain management within the construction industry

2.2.1 Supply chain management in construction

In the previous sections, SCM has been discussed largely from its background in the manufacturing industry however, SCM within the construction industry is different in a number of ways. Cox et al (2006) claimed that academic writers have been too narrow in their work of SCM to date, as they claim that professionals have passively copied ideas of supply chain partnering from Japanese and Western automotive industries. While this assessment is perhaps overly critical, it does highlight the need to contextualise SCM within the construction industry. This section provides an introduction with specific focus on SCM within the construction industry.

Hatmoko (2008) approached this task in a logical manner and begins the discussion by summarising a number of SCM definitions from a construction perspective. Hatmoko's approach here is largely descriptive and he claims that the definition given by O'Brien (2002) is the most '*straight forward*'. O'Brien (2002) stated that, "SCM is the process of contractors and suppliers producing, delivering and installing materials for use on construction projects".

Figure 3 Construction supply chain conceptual view (O'Brien, 2002)

Hatmoko used this as a basis for his own definition but offers no justification as to why this definition is adopted over any of the other definitions that had been proposed up to that point. Hatmoko's definition is as follows:

> Supply chain management is the process in which clients and contractors collaborate and the main contractor is responsible for the project's coordination in order to produce, deliver, install, and utilise materials, labour, information, equipment and temporary work, together in construction projects.

Although Hatmoko's decision making lacks transparency; the definition is useful in a number of ways and it is clear that it draws on other important definitions to date. For example, in the refined definition, Hatmoko has clearly incorporated four roles, developed by Vrijhoef and Koskela (2000), of supply chain management in the construction industry. Hatmoko referred to this meta-analysis as relevant to the construction supply chain management literature but does not explain explicitly why these roles were incorporated in the new definition. Nevertheless, the decision to include the client within the definition is a valid decision, as this element is also a feature of other definitions of supply chain management from the construction perspective (Tommelein et al, 2003). The importance of the client is also highlighted well in Elfving's (2003) definition:

> Supply chain management is the management of all the processes that are required to deliver a service or a product for a customer through a network of organisations with minimum waste and maximum value.

It can be argued that this type of definition has a key advantage over that offered by Hatmoko (2008). The key strength in Elfving (2003) definition is the reference to '*maximum value'*. Hatmoko (2008) and others before him have been entirely convincing in explaining the benefits of effective supply chain management. The justification to develop supply chain management has been further encouraged by the rewards experienced within both manufacturing and construction industries. Some significant benefits of effective SCM include reduced inventory level and supply cost; and increased inventory turnover rate, productivity and sales and profit (Venkataraman, 2004, Greenwood, 2004, Vrijhoef, 2009). Greenwood's case study provides 'saving' figures of 31% that have been attributed to effective supply chain management. While it can be argued that it is difficult to establish cause and effect relationship in these types of case studies, it is undeniable that effective supply chain management is about reducing costs, reducing time and improving quality.

It can be argued then that it would be worthwhile for any definition of supply chain management to make reference to these key aims. It is surprising that very few of the definitions of supply chain management within construction highlight the 'added value' aspect of supply chain management. The main exceptions to this trend include the definitions given by Elfving (2003) above, Bowersox, Closs and Cooper (2002) and Sweeney (2007)

Bowersox, Closs and Cooper (2002) claimed that supply chain management,

> Supply chain management consists of firms collaborating to leverage strategic positioning and to improve operating efficiency.

Sweeney (2007) claimed that supply chain management is the,

> Supply Chain Management is the systemic, strategic coordination of the traditional business function and tactics across these business functions.

While these definitions of supply chain management appear far too simplistic in comparison to Hatmoko's more detailed one; they do discuss value adding, reducing costs or maximisation (Elfving, 2003) and this is an element that should not be excluded from any definition of supply chain management. Consequentially, the definition of supply chain management that is used in this research will highlight not only details of the supply process but also the centrality of cost and customers. The definition of supply chain management that will be used in this research is, "all activities involved in delivering a product from raw material through to the customer including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer and the information systems necessary to monitor all of these activities to reduce cost, time and inventory levels and improve customer satisfaction".

The author believes that the reason for adopting this definition is related to the research purposes and points of interest, in addition to the clear and straight forward clarification that includes the main significant elements of supply chain management.

2.2.2 Construction logistics

According to Almohsen and Ruwanpura (2008) construction logistics is considered a process which is multidisciplinary that contains schedule control, processing and handling, storage, materials supply, manpower supply, equipment location, site infrastructure, physical flow of the site and the management of information that is linked to the physical flows and services. The above activities are performed in the construction process. Within a construction company, activities, logistics tasks and functions can be separated into: site logistics and supply logistics. Site logistics are concerned with the planning of site physical flow, directing and controlling on site activities, organizing; e. g. definition of activity, management of handling systems, safety equipment, site layout, sequence etc. Supply logistics are associated with the production process activities, e. g. acquisition of resources, supply planning, supply resources (materials, manpower and equipment) specification, storage control and transport.

On the other hand, Wegelius-Lehtonen and Pahkala 2002) had another view about logistics in construction. Lehtonen and Pahkala focused on material type and classified the delivery process into three types: customized materials, normal materials and small purchases. According to Wegelius-Lehtonen and Pahkala (2002),

> Materials that are designed to order are classed as customized materials whereas are make-to-stock or make-to order materials are classed as small purchases and standard materials.

The same authors argue that the delivery process of these three types suffers from many problems related to the changes in design, storing and shortage, damages, packaging and wastes. Regarding standard materials, the most important concern is materials flow. The reason can be traced to the problems and difficulties within the process of storing and handling typical heavy and bulky standard materials on construction sites. Thus, a clear and accurate process of planning for the transportation and organising the unloading areas on site is required prior to the process of ordering materials. By contrast, information flows are the most important concern for customized materials and failure in gathering and obtaining the required information may cause serious problems that may lead to disruption of the project.

Discussed earlier, the Council of Logistics Management (CLM, 2007), definition of logistics management as a segment of SCM that controls, plans and implements the forward and reverse flow of goods and storage. Logistics requires adjustments and modifications in order to suit both the construction industry context and the framework, as it is classed as part of supply chain management which also requires adjustments and modifications. Construction supply chain characteristics must be understood in order to grasp the context of the construction industry in detail.

2.3 Construction supply chain characteristics

One of the main characteristics of construction supply chains is that it can be very complex particularly in large projects. This complexity can be attributed to the variety of site materials and parties (suppliers and sub-contractors) required for a construction project. The project can become more complex the more people are involved. i.e. first tier, second tier suppliers and other tiers of sub-contractors etc. Moreover, there is a correlation between the increase of the scope of the project with the complexity of the supply chain, as more manpower, parties and materials are necessary for the completion of the project and this requires a great deal of planning, organising and collaboration between them which may cause the complexity.

A large construction company may interact with hundreds or thousands of suppliers and sub-contractors per a year in order to deliver a project, for example, in 1999 the Wates construction company paid more than 3000 suppliers and sub-contractors that were involved in projects they delivered. (Scott et al, 2001)

Moreover, Vrijhoef (1998) carried out research on residential building projects and contributed that supply chains in construction are usually converging, fragmented, make-to-order and temporary, described as follows:

1- Converging supply chain:

Normally in construction projects, operation capacity, documents, materials etc., should be assembled and delivered to site by both subcontractors and suppliers under the main contractor's supervision. Usually, a limited number of people or one is the end user. All resulting in making the construction supply chain to be converging unlike the manufacturing supply chain, which is most likely to be diverging, as illustrated in figure 4.

Figure 4 Comparing construction converging supply chain to manufacturing diverging supply chain adopted from (Vrijhoef, 1998)

2- Fragmented supply chain:

Fragmentation is one of the most important characteristics in the construction process. During various stages of the process, contractors, suppliers and other participants are active. Regular changes regarding authority and distribution of responsibility occurs throughout the process.

3- Make to order supply chain:

Most construction projects are considered to be customer driven. This can be the result of the end user's tradition to take the initiative and start a construction project. The end user becomes involved in the whole production process, as presented in figure 5.

Figure 5 Make to order supply chain in construction adopted from (Vrijhoef, 1998)

4- Temporary supply chain

For any construction project, on completion, all participants and companies involved are normally dismissed and this can be traced to the project based nature of construction. All participants in the project must finish their roles and duties as a consequence. This short term partnership with different members may cause problems and fluctuations in performance and productivity.

On the other hand, Muya et al. (2001) pointed out other characteristics of the construction supply chain, detailed below:

1- Primary supply chain – this supply chain deliver material incorporated in the final stage of the construction process, such as: sub-assemblies, components, raw materials and electrical and mechanical equipment.

2- Support chain - this chain is responsible for providing expertise and equipment that smooth and facilitate the construction process such as: scaffolding and excavation supports.

3- Human resource supply chain - responsible for labour supply and supervisory staff supply as part of construction process inputs.

Taking into account that construction industry characteristics are different from other industries, for example, the manufacturing industry, this will certainly differentiate the construction supply chain from the other industries. To sum up, the construction supply chain consists of the human resource supply chain, the primary chain and the support chain and it is characterised as temporary, make-to-order, complex and converging supply chains.

2.4 Stakeholders and construction supply chains

The Oxford dictionary (2015) defines a stakeholder as “a person with an interest or concern in something, especially a business". In a broader context, suitable to the construction industry, construction supply chain stakeholders can be defined as people, parties or organisations which are involved in and/or have an interest in construction supply chains. Generally speaking, stakeholders are owners/clients, main contractors, sub-contractors, suppliers and the design team.

Edum-Fotwe et al (2001) proposes a more detailed classification of the stakeholders' involvement in the construction supply chain. The same author argues that their involvement may vary depending on the stage of construction.

In order to gain a congruous viewpoint and gain an insight into the main stakeholders within the supply chain, main contractor, client, sub-contractor and supplier definitions are described as follows:

1. Clients

The client is the initiator of construction projects, making the decision to procure construction work and subsequently decides the procurement system (Briscoe et al., 2004). In order to carry out a construction project, the client should employ a contractor by way of competition (tendering) or negotiation (partnering). Consequently, the client holds a strategic position and influences projects by way of decisions taken on setting up projects and the procurement system (Bresnen and Haslam, 2003). Therefore, in order for supply chain integration to succeed, the client is considered as the most important factor (Briscoe et al., 2004).

The level of experience of the client influences the way in which a client comes to a decision (Bresnen and Haslam, 2003). Previous experience of the construction industry also has a considerable influence regarding the interaction process between the client and industry professionals i.e. designers, contractors etc. (Gameson, 2001). According to Gameson, clients within the construction industry can be classified by two characteristics, primary or secondary constructors together with their level of experience in construction. Primary clients are those where their main business is the construction of buildings and their primary source of income is derived from the same, for example property developers. Secondary clients are those whose outlay in relation to the construction of buildings comprises a small percentage of their gross turnover and the constructed buildings are necessary to carry out a specific business activity, i.e. manufacturing. Clients may also be classified as either experienced or inexperienced. Those with "recent and relevant experience in the construction of particular types of buildings and have well-established access to construction expertise whether that be externally or in-house" are classified as experienced whereas those which have none of the above are classified as inexperienced. The experienced clients will ultimately have influence over decision making between themselves and construction professionals and can therefore have an impact on the project's performance.

2. Main Contractor

The main contractor holds responsibility for the timely completion of the project, within budget and to a high quality. The main contractor's role is significant and within construction supply chains, his/her position is strategic as a 'facilitator' in order to control and manage requirements from both the design team, client and subcontractors (Cox et al., 2006).

The main contractor is usually responsible for the selection of suppliers and subcontractors prior to the commencement of the project. However, suppliers or subcontractors can be nominated by the client avoiding selection by the main contractor. The client may nominate them due to recommendations from designers. Other reasons for sub-contractor nomination (Muya, 2001), include: the specialist techniques provided by a specialist sub-contractor and a level of quality of work which a specialist contractor can provide also where necessary, the need to put an order in place for specialist work prior to the selection of the main contractor.

3. Subcontractors

In construction projects, sub-contractors also play an important role working in collaboration with the main contractor assisting them to carry out specialist works. It is common that 90%

of construction projects are sub-contracted (Vrijhoef, 2009), subsequently 90% of a main contractor's gross turnover is contributed by sub-contractors (Ndekuri, 2006). The sub-contractor's contribution to the main contractor is therefore vital to the successful outcome of the project and the earlier their involvement aids the relationship with the main contractor which enables the parties to build a trustful relationship (Vrijhoef, 2009).

4. Suppliers

Usually speaking, suppliers are those parties which supply materials to a given construction project. The international organisation for standardisation (ISO) 9000: 2015 define a supplier as, an organisation or a person that provides services or products. Suppliers can be external or internal to an organisation. External suppliers provide services or products to other organisations while internal suppliers provide services or products to individuals within their organisation.

Moreover, suppliers have a great impact on a construction supply chain, responsible for the supply of components and/or materials for projects, to be carried out in a timely manner and within cost (Venkataraman, 2004), which may contribute up to as much as 50-60% of the project's total cost. Important factors relating to suppliers are those such as: delivering of supplies on time could lead to a shorter cycle time, reduction of inventory levels and improving service level (Venkataraman, 2008). Therefore, it is paramount to manage suppliers within the supply chain in order to obtain high performance levels and the required outcome.

Figure 6 Stakeholders of the construction environment (Courtney, 1999)

Figure 6 presents the various stakeholders of the construction environment based on Courtney (1999) work. In summary, main contractors, subcontractors, clients and suppliers, combined play an important role in construction supply chains and each has a strategic position within the chain. All face unique problems which must be managed in order for the projects in the construction industry to be successful, discussed below in more detail.

2.5 Construction supply chains and construction industry problems

The construction industry and its supply chain suffer from many problems that affect it in a negative way. According to Yeo and Ning (2002) many problems affect the construction industry such as: budget overruns, delays, low profit margins and many legal and counter claims.

Moreover, O'Brien, Formoso, Vrijhoef and London (2009) stated that construction supply chains are filled with wastes and issues caused by short-sighted controls and the characteristics of the construction supply chain reinforce the problems in the construction supply chain which may hinder the application of supply chain management to construction.

Construction industry problems can also be seen in Cox and Townsend (2006) work from demand and supply perspective. They categorised problems in the construction industry in terms of supply, demand and common issues.

According to Cox and Townsend (2006), demand issues contain inappropriate selection criteria, discontinuous and low demand problems, inappropriate allocation of risk and frequent changes in specification discussed as follows:

- Inappropriate selection criteria: this problem refers to the practice of awarding a contract in the construction industry to the contractor that offered the lowest price, disregarding to the value of the offer. As a consequence, the awarded contractor may provide lower quality and service which may lead to some problems like: less trust, resistance to design changes and claims for additional fees.

- Discontinuous and low demand problems: the economic recession and the difficult financial situation leads to a decline in the public investment which results in such problems occurring.

- Inappropriateness of risk allocation: refers to the imbalanced distribution of risk in the project concerning the main contractor and client.

- Frequent changes in specification: this problem is due to the client and occurs while the project is underway and this causes serious implications on the plan and indeed the cost.

According to Cox and Townsend (2006), supply issues contain poor public image, inefficient methods of construction and poor quality as follows:

- Poor public image: the construction industry failed to retain and attract highly qualified and experienced individuals. In addition, certain conditions are attributed to the industry such as: dangerous, uncertain, low job security and unhealthy environment.

- Inefficient method of construction: this problem is common in the house building sector. The optimal solution to overcome this problem is by making an integration process of the design with the construction method to maintain projects buildability.

- Poor quality: Yeo and Ning (2002) stated that poor quality stems from both the lack of and simplicity of rules to enter the construction industry. This thing allowed new and inexperienced companies to enter the industry, destroy its reputation and affect the quality of the whole industry.

Moreover, Cox and Townsend (2006) stated that the common issues contain fragmented industry structure, adversarial culture, inadequate investment and poor management as follows:

- Fragmented industry structure: fragmentation here refers to the size and number of construction companies, diversity of both trends and professionals and contractors intend to use subcontractors but sub-contractors are using other sub-contractors to carry out the work. Some of the sub-contractors are not trained or do not have sufficient experience to meet the job specifications, which may lead to a fragmented industry structure.

- Adversarial culture: this problem has been recognised for years and may lead to some negative influences on the client and the contractor. Moreover, this problem may lead to a failure in in the adoption of the new procurement process.

- The inadequate investment in training: a clear lack of research and development exists within the construction industry which may affect the quality.

- Poor management: this could occur at site level or due to the company which may lead to low performance levels.

To summarise, the problems present in construction supply chains conform to those existing in the construction industry and are difficult to cope with. The construction industry itself may hinder efforts to remove obstacles and aid performance. Vrijhoef and Koskela, (2000) stated:

> With regards to the improvement of performance in construction, the lack of accessibility and availability of performance data is one of the greatest obstacles. One criticism of construction companies is that, 'they don't know what they don't know' and it appears that maintaining performance registers is not common practice.

Figure 7 illustrates the varying problems that arise in construction supply chains.

Figure 7 Construction supply chain problems progression adopted from Vrijhoef and Koskela (2000)

However, performance measurement of supply chain management has not been given sufficient attention. Performance measurement of supply chain management is discussed in detail next.

2.6 Supply chain performance measurement

2.6.1 Measuring performance in the manufacturing industry

Issues relating to supply chain performance measurement have been addressed by some researchers, for example (Otto and Kotzab, 2003, Gunasekaran et al., 2004, Al-Khalil et al., 2004). In literature, various measures of supply chain performance have been described by

Bhatnagar and Sohal (2004), as seen in table 5. Same authors argue that, according to these performance measures, " *in all contexts, no set of stable measures to assess supply chain performance can be used* ". These set of measures are normally related to quality, lead time, flexibility, inventory and customer service.

Author	Performance measure
Levy 1995	Final good average inventory, Fulfilment of demand
Christopher 1992	Completeness of order, The cycle time of an order, The level of reliability in a delivery
Sharman and Lambert 1990	Responsiveness, Defects level, Lead time, Delivery performance
Lee and Cohen 1990	Lead time, Final goods inventory, Inventory level of work-in-progress, Material inventory, Frequencies of stock outs, Fill rates
Billington and Lee 1992	Cycle time of the total order, Delivery variability average, Order response time, Fill rates of line items, Inventory turns

Table 5 SCM performance measurement in the manufacturing industry (Bhatnagar and Sohal, 2004)

The performance measures presented in Table 5 cover the period 1990-1995 and are mainly related to the operational level of supply chain management.

Moreover, Beamon (2002), carried out further research to update the measures used between 1990-1995. argues, three types of performance measures should be incorporated and assessed in a supply chain measurement system, namely: resource measures (R), output measures (O) and flexibility measures (F). Beamon argues that each of the above must be measured as all three are crucial to the overall performance success in relation to the supply chain. The reasons given are: the management of efficient resources is vital to profitability (R), with unacceptable output, customers will inevitably turn to different supply chains (O), where an uncertain environment exists, supply chains need to adapt and respond to change (F). Three types of measures and their components are displayed in below in table 6.

Resources	Output	Flexibility
➢ Cost ➢ Personnel requirement ➢ The usage of energy ➢ The level of inventory ➢ The utilization level of equipment	➢ Errors in shipments ➢ Profit margins ➢ Complaints from customers ➢ Response time from customers ➢ Deliveries on time ➢ Lead time in manufacturing ➢ Sales	➢ Flexibility level of new products ➢ Flexibility level of delivery ➢ Flexibility level volume ➢ Mix flexibility

Table 6 SCM measurements and components adapted from Beamon (2002)

On the other hand, Otto and Kotzab (2003) developed supply chain management performance metrics formed on the following perspectives: operation research, system dynamics, strategy, logistics, marketing and organization strategy, presented in table 7. It is believed that with the six perspectives, a set of holistic and comprehensive metrics could be established in order to make an assessment of the supply chain.

Operations research	**System dynamics**	**Logistics**	**Strategy**	**Organisation**	**Marketing**
Cost of logistics per unit	Inventory level cumulative	Level of inventory flexibility	Focal organisation	Time needed to network	The cost of distribution per unit
Level of service	Utilisation of capacity	Integration	Return on investment	The cost of transportation	The cost of channel / market share
Delivery time	Adapting time	The cycle time of an order	Time needed to network	Relationships density	Level of satisfaction for customers
		Lead time			
	Time lags		Time needed to market	Flexibility	
	Stock-outs				

Table 7 Supply chain management performance metrics (Otto and Kotzab, 2003)

The above discussions are mostly related to the manufacturing industry which is where the supply chain management theories originated initially and it should be noted that supply chain practice between construction and manufacturing industries is very different (Naim, 2003).

The following section discusses performance measurement in supply chain management within the construction industry.

2.6.2 Measuring performance in the construction industry

Proverbs and Holt (2000) stated that measuring the performance of construction is a difficult and complicated process. They believe that up until this point in time only a few researchers have specifically concentrated their research on the measurement of supply chain performance in this industry. Presented in table 8, is an attempt to measure performance according to contributions gathered by Vrijhoef (1998).

Author	Variables	Assessment method
Plemmons et al 1995	Materials management effectiveness	Effectiveness benchmarking process
Wegelius and Lehtonen 1995	Logistics process delivery time, accuracy and cost	Logistics process analysis
Smith et al 1996	Disruptions of productivity interruptions and variation	Variations analysis
Formoso et al 1996	Supply chain process deviations	Deviations identification
Lewis et al 1996	Supply chain process delays	Classification and definition of delays
O'Brien 1997	Production cost, deliveries, uncertainty and lead time	Integrated performance and cost analysis

Table 8 Performance measurement in the construction industry (adapted from Vrijhoef (1998))

The lists are in relation to the effectiveness of materials management, processes relating to logistics, productivity and supply chain processes. Moreover, additional research has been identified since Vrijhoefs work within the literature relating to supply chain management performance measurement. Wegelius-Lehtonen (2001) suggests other types of measures, offering a framework for performance measurement relating to construction logistics. The framework consists of two dimensions in order to classify performance measures: the focus of measure and the use of measure, discussed as follows:

- Focus of measure

Focus of measure reveals the organisation level to which the measures should be used, e.g. project level or general company, and material supplier level or specific sub-contract. The reasoning behind this classification is different measures are needed for different levels of organization. Relating to construction logistics, measures may be utilised at three levels as follows:

1- Focus on performance of special sub-contractors.
2- Performance of individual projects.
3- Performance at company level.

- Use of measure

Use of measure shows the area of application to which the measures should be applied, for example. monitoring and improvement measures. It is necessary to apply monitoring measures in order to control and screen the day-to-day operations of companies. Improvement measures are critical for both new development and co-operation projects where the aim is to establish the current logistical performance level and the potential for improvement.

Moreover, Al-Khalil et al. (2004) carried out research in this area and adopted twelve key measures, proposed by Plemmons and Bell (1995), in order to measure how effective materials management is for the purpose of industrial projects. Illustrated in table 9 next is the same authors work. Venkataraman (2004), in line with Al-Khalil et al. (2004), suggested metrics for project supply chain performance which has been classified into 4 categories which are: cost, time, flexibility and quality.

It should be noted that the majority of the measures which have been described above are taken from literature studies and some have been adopted from literature in manufacturing. In

Attribute	Measures	Measured by
Accuracy	Problems with materials receipt	Percentage of error free line items received
	Inventory accuracy in the warehouse	Comparing a data sample in the materials data base with the inventory in the warehouse and controlled areas
Availability	Materials availability	The sum of material line items requested
		The sum of material line items issued
Cost	Time lost in construction	Percentage of wasted construction time due to inadequate material planning
	Total surplus	Percentage of surplus materials waste value to the total materials purchasing cost
Quality	Tagged equipment's jobsite rejections	Tagged equipment rejection percentage
Timeliness	Lead time of material withdrawal request	Ratio of average MWR lead time and MWR planned lead time
	Commodity vendor timeliness	Percentage of on time supplier deliveries
	Processing time of material received	The percentage of materials received and processed within the same day and next day i.e. day after delivery
	Receipt duration of purchase order to material	The average to the planned durations ratio
	Commit, bid and evaluate lead time	Commit, bid and evaluate average duration in days to the planned duration of materials purchase
	Procurement lead time	The average lead time of procurement in days' ratio and the planned ratio of procurement lead time

Table 9 Effectiveness measures obtained by Al-khalil et al. (2004)

light of this, Muya (2001) was curious to learn the importance of the measures from the perspective of suppliers and contractors. Muya conducted research on the logistics of constructions materials and contributed that both suppliers and contractors rated performance indicators in the very same order; (item 1) most important, (item 2) least important.

1. Reliability (suppliers' ability to deliver the correct products at the specified quantity and quality, to arrive undamaged and on schedule).
2. Cost-effectiveness (the cost of service which the customer is satisfied with)
3. Flexibility (responsiveness to the customers' changing needs)
4. Lead time (supplier quoted lead time)
5. Value-added (service which exceeds the basic requirements of service)

Unsurprisingly, both suppliers and contractors ranked reliability highest as the most important performance indicator. It was obvious to both that reliability, with all that entails, is paramount.

The performance of a construction site is heavily influenced by how much they can rely on material supply. Any delays in relation to supply and delivery of materials will naturally delay the process on the construction site and in particular, where the activity is on the critical path. The very same situation would arise should other flows in supply chains be delayed, i.e. plant/equipment flow, labour flow or information flow etc. Most of the current research about SCM in construction is descriptive and lacks any numeric outcomes to measure its impact on project performance. This influenced the use of simulation in order to provide numerical outcome and provide data regarding the impact of each flow of the construction supply chain on project performance, both each flow separately and combined. Moreover, using simulation enables the process of isolating other factors to ensure that the outcome is only related to the SCM impact. In addition, O'Brien, Formoso, Vrijhoef and London (2009), stated that simulation is a reputable and proven type of analysis in construction management and construction engineering. As the main focus of this research is the impact of supply chain management on construction projects in terms of time. Time delays would be used to measure the impact of supply chain management on construction residential housing projects performance, as Al-Khalil et al. (2004) proposed.

2.7 Comparing supply chain management in construction and manufacturing

Considering the construction and manufacturing industries have various characteristics which are different, clearly supply chain management in the two industries will also be different. Being project based, fragmented with converging supply chains, the construction industry can be considered as a product, rooted in place and fixed position manufacturing (Ballard and Howell, 2001).

In manufacturing, the manufacturing process may be considered separate to the product. Raw materials go through certain processes and result in a finished product. This is not the case in construction, you cannot separate the process from the end product as the building 'grows' by way of the techniques, methods and the organisation it is attached to (Scott et al., 2001). Illustrated following in figure 8, Venkataraman (2004) shows comparisons of a supply chain relating to a project organisation and a make-to-stock manufacturing company.

Figure 8 Typical supply chain for a make-to-stock manufacturing company and project organisation (Venkataraman, 2004)

Each of the organisations within the supply chain has both inbound and outbound elements. The inbound components can entail raw materials and components or suppliers together with warehouses and transportation links and concludes with the company's internal operations.

Outbound components start when outputs are delivered by the organisation to customers, including retail distribution centres, wholesalers and transportation companies ending with the final customer. Usually, in a project organisation, the outbound supply chain is longer than the inbound supply chain. The reverse is the case concerning the make-to-stock manufacturing company. On the other hand, Ghurka (2003) has an alternative perspective on the differences between the construction supply chain and the manufacturing supply chain, displayed as follows in table 10.

Construction supply chain	Manufacturing supply chain
Widely used as build to order	Widely used as build to stock
Defined and specific end product	Less specific and wider end users
Unique project design and specifications of material that are not repeatable in general	High standardisation degree with repeatability
The demand forecast is uncertain	Planning and demand forecast can be carried out in a reliable way
The production process involves several organisations that have different objectives	In general, the production process is the responsibility of one organisation
The distribution network and suppliers are specific to the project	The distribution network and suppliers are predefined
Several suppliers providing to an explicit end user	Several suppliers providing a wide range of users

Table 10 Differences between construction and manufacturing supply chains (Ghurka, 2003)

As can be seen from table 10, the construction and manufacturing supply chains have some differences resulting from the various unique characteristics of each industry which influenced the supply chain to be different from one another. Each industry supply chain is unique and managing it should be from the industry perspective. The following section will shed light on the process of integrating supply chain management in the construction industry.

2.8 SCM integration

According to Hall (2001), improving communication and in particular integration through the supply chain is necessary in order to progress and develop the construction industry. To facilitate the improvements several issues need to be addresses. Firstly, a shift from the selection of contractors based on lowest bid to selection based on best value. Secondly, a shift from contractor/client orientated relationship to involve all parties within the supply chain and thirdly, a shift from a disbanded project team on completion of a project to a continuation of the supply chain relationships in new projects.

Various researches have been carried out regarding the willingness of the construction industry to adopt the philosophies of integration (Khalfan et al., 2001, Khalfan et al., 2002). Interviews were also conducted by Briscoe et al. (2004), with many SME's in order to assess the appropriateness of their skills, attitudes and current knowledge to achieve an improved supply chain integration.

2.8.1 Integration barriers and drivers

Tan (2010) identified five key components when moving towards a more fully integrated supply chain:

1. Transformation in corporate culture
2. Communication and trust between all relevant parties
3. Sharing of knowledge/information
4. Evaluating suppliers as part of the development process
5. Sharing common objective regarding both increased efficiency and waste elimination

It is vital to remove the deep-seated barriers of traditional relationships within the construction industry and replace it by introducing a 'change management framework', at operational level, in order to implement supply chain management.

The barriers relating to integration are attributed to an adversarial contractual relationship, lack of trust and fragmented project deliver. Dainty et al. (2001b) proposes solutions to this deficiency within the supply chain, namely:

1. The formal integration of subcontractors and suppliers regarding reporting and communication with the organisational structure of the project.

2. The development of soft skills and communication skills of the project staff Akintoye et al. (2000), also identified integration barriers including: workplace culture, unsuitable support structure, uncommitted senior managers, trust issues and unfamiliar regarding the concept of supply chain management and its implications. According to Barratt (2004), barriers include extensive use of IT for the implementation of integration and collaboration issues i.e. with who should we collaborate within the supply chain.

2.8.2 Integration benefits

Supply chain integration aids to the efficiency and stream-lines the objectives of all parties involved helping to achieve goal congruence, productivity and the minimisation of waste (Maqsood and Akintoye, 2002). To implement supply chain integration, the following are required according to Swan et al., (2001): a shift from the traditional contractual framework, the integration of organisational processes regarding all participants together with long term commitment and trust. Hall (2001) is confident that integration would benefit the client regarding the overall delivery of the final project but moreover, increased profit margins, decreased aggravation and stress, development of both no-blame culture and of mutual understanding and the attainment of enhanced reputations for the contractor

2.8.3 Integration culture requirements

Barratt (2004) suggests a 'collaborative culture' for the integration and collaboration of the supply chain within the construction industry which consists of the following elements:

1. Internal and external trust
2. Mutual benefits
3. Exchange of information within the supply chain
4. Quality of information and transparency of information
5. Good understanding and communication between all parties
6. Goal congruence
7. Corporate emphasis/attention on SCM

Dainty et al. (2004) proposes required changes for supply chain integration as follows: early involvement of all parties, education of project staff, fair payment, have knowledge of the benefits of integration, be familiar with and have an understanding of new contractual documents.

2.8.4 Effective integration

Vrijhoef (2011) believe that should all parties within the supply chain be targeted, including the main contractor, subcontractor and suppliers, often referred to as ‘downstream strategic alliances’ (DSA’s), overall costs of construction would reduce. They also conclude subcontractor and supplier early involvement is as necessary as early contractor involvement. This early involvement of all parties would allow the exchange of expertise which may help to reduce costs furthermore, early involvement integration would enable suppliers to be service providers as oppose to providers of products.

To summarise, Supply chain integration aids to the efficiency and stream-lines the objectives of all parties involved helping to achieve goal congruence, productivity and the minimisation of waste. To implement supply chain integration, a shift from the traditional contractual framework, the integration of organisational processes regarding all participants together with long term commitment and trust.

The integration process of supply chain management would benefit the client regarding the overall delivery of the final project but moreover, increased profit margins, decreased aggravation and stress, development of both a no-blame culture, mutual understanding and the attainment of enhanced reputations for the contractor.

2.9 Summary

This chapter elaborated supply chain management in both the manufacturing and construction industries, its evolution, main concepts and measurements. It is quite clearly, considerable differences exist when comparing the manufacturing and construction industries as within the supply chains. The differences may be found in all stages of construction i.e. pre-construction, during construction and post-construction. Researchers will unavoidably have these differences brought to their attention when reading supply chain management literature relating to the manufacturing industry which is to be applied in context to the construction industry. Supply chain management in construction, as mentioned previously, is a relatively new concern which over the last decade has received attention from numerous researchers in the manufacturing industry. Moreover, this chapter elaborated the process of measuring supply chain performance and integrating supply chain management in construction.

The following chapter illustrates the research design, worldwide philosophies in research, the steps that are taken to finalise the research aim and objectives and the research arrangements data flow diagram which provides an insight about all activities and tasks in this research.

Chapter 3

Research methods adapted

This chapter discusses the existing research methods, gives an overview of the simulation theory, discusses the adopted research methods in this thesis and a description of the triangulation carried out by this research. The structure of this chapter is as follows:

3.1 Research methods overview: this section discusses the major research methods, classifications and further categorises each classification providing definitions and use.

3.2 The simulation process: this section discusses simulation, its uses, steps and classifications.

3.3 The adopted research methods: this section discusses the research methods adopted in this thesis. As mentioned in the introduction chapter, preliminary investigation, survey and simulation are the methods used and will be discussed in detail.

3.4 Triangulation: this section will define the triangulation concept and its importance. Also discussed are the different types of triangulation and those types used in this thesis.

3.1 Research methods overview

According to Collis and Hussy (2013) a research can be classified into four categories which are: the logic, process, purpose and the outcome. The logic clarifies whether the research is moving from specific to general or vice versa. Under this category the research can be classified as inductive or deductive. The second category is the process which reveals the process of data collection and analysis. Under this category the research can be classified as qualitative or quantitative. The third category is the purpose which shows the reason for conducting the research. Analytical, descriptive, predictive and exploratory are classifications under that category. The research outcome is the fourth category which reveals whether the research is going to make a contribution to knowledge or solve a particular problem. Under this category the research can be classified as basic or applied research. The following table 11 clarifies the research classifications and categories.

Research type	Classification base
Inductive or deductive research	Logic of the research
Qualitative or quantitative research	Process of the research
Analytical, descriptive, predictive or exploratory research	Purpose of the research
Basic or applied research	Research outcome

Table 11 Research main classifications (Collis and Hussey, 2013)

3.1.1 Analytical, descriptive, predictive or exploratory research

Explanatory or analytical research is a protraction of descriptive research that aims to clarify phenomena by measuring and understanding the relations between them. This type of analysis, explains and describes how and why different things are happening. For this kind, why and how are the most appropriate question words to use.

Descriptive research attempts to recognise and identify characteristic information of a certain issue or problem. This research attempts to identify phenomena as it exists naturally. Where, how much, how many, what or who are suitable questions to ask.

Predictive research targets to simplify using information from analysis by expecting a specific phenomenon based on hypothesis. In other words, this type aims to estimate the chance of an occurrence. Where, what, who, how many and how much are the appropriate questions to ask.

Exploratory research is concerned with finding hypotheses, ideas or patterns. This research is used when there are a limited number of researches to refer to. What, why, how, how much, how often, how many and where are the appropriate questions to ask for this type of research.

Following, table 12, illustrates research methods of classifications based on the research purpose.

Research type	Description	Aim	Examples of appropriate methodologies	Appropriate question and words
Exploratory	Used when there are few researches or studies that cover this particular topic, therefore it is hard to extract the information from such studies.	To look for ideas, hypothesis and patterns, rather than confirming the validity or the invalidity of such hypothesis.	Qualitative approach • Experiment • Case studies • Observations • Historical analysis	Why and how
			Quantitative • Survey • Secondary data analysis	How much, how many, how often, who, where, what
Descriptive	Describing an actual event or phenomena relating to its existence.	To analyse and extract information from a particular issue.	Quantitative • Survey • Secondary data analysis	What, who, how, where, how many, how much
			Quantitative • Experiment • Case study • Ethnography • Participant observation	What, who, where
Explanatory or Analytical	A continuing description of previous researches.	To recognise a specific phenomenon by discovering the relationships around them.	Qualitative • Case study • Experiment • Participation observation • Case survey • Ethnography	Why, how
Predictive	Forecast the probability of a certain case.	To comprehensively understand the analysis by predicating different cases that are derived from the hypothesised general relationships.	Quantitative • Longitudinal • Survey • Secondary data analysis	What, who, where, how much, how many.
			Qualitative • Experiment • Case study • Grounded theory • Ethnography • Participant observation	What, where, who

Table 12 Research methods classification in relation to research purpose (based on Collis and Hussey (2009)) findings

3.1.2 Quantitative and qualitative research

Depending on the approach, research can be categorised into qualitative and quantitative. According to Creswell (2009), quantitative data is a method of research, where the researcher uses positivist claims so as to: develop the knowledge that is based on the prior investigation which can be particularly seen in (i.e. use of observation and measurement, cause and effect thinking, test of theories, reduction to specific variables and hypothesis with questions), employs investigation strategies and inquiry (i.e. surveys and experiment), also gathers data on pre estimate instruments which produce statistical data. This type of research focuses on understanding a certain phenomenon by gathering and analysing numerical information and running numerical tests (Creswell, 2009). This approach is deductive, which could be more applicable on research areas or mature subjects and it could also be applied in a different questioning area like what and how many. The results are normally accurate and easy to both understand and interpret. However, the results generally would cover the area that we focused on during the study as results that do not match the hypothesis would normally be hard to find due to the fact that the model has not been designed to measure them (Yin, 2009).

Qualitative research is explained as follows: “a research where the inquirer regularly makes knowledge claims, mainly founded on constructivist perspectives (i.e. meanings socially and historically constructed, the multiple meaning of individual experiences, with the intention of developing a pattern or theory) or supportive perspectives such as; collaborative or change oriented or both, issue oriented or political,” (Creswell, 2009). This research could be more subjective as regards to examining and reflecting on perception in order to acquire more understanding of human and social activates. This approach could be more suitable for the more undeveloped subjects and areas of research that are uncertain or still unclear and that require answers like why and what (Yin, 1994).

Creswell (2009) contributed a mixed approach in addition to the previously mentioned approaches. This method of approach is “where the researcher is inclined to base claims of knowledge claims on practical grounds (e.g. pluralistic, problem-centred, consequences-oriented,)”. In order to have a better understanding of the research problem, the mixed approach accommodates strategies for investigation that require gathering data either sequentially or simultaneously and, using numbers combined with text-based information. Following in table 13 is a summary of these three approaches in more detail.

	Qualitative approach	Quantitative approach	Mixed method approach
Philosophical assumption	• Deductive • Corroboration • Conductive knowledge claims	• Post positivist knowledge claims	• Pragmatic knowledge claims
Strategies of injuries	• Phenomenology • Ethnography • Grounded theory • Narrative • Case study	• Experimental • Surveys	• Concurrent • Sequential • Transformative
Methods	• Emerging approaches • Open ended questions • Text or image data	• Predetermined approaches • Closed-ended questions • Numeric data	• Both open and closed ended questions • Both qualitative and quantitative approaches • Both emerging and predetermined approaches
Practise of research	• Gathers participants' answers • Position herself or himself • Highlights the single concept or phenomena • Brings personal values into the study • Studies the context or setting of participants • Tests the accuracy of findings • Creates an agenda for change • Cooperates with participants • Extract the constructive meanings from the data	• Test the validity of the theories. • Identify the variables elements for the study • Link those variables with the questions and hypothesis • Uses standards of reliability and validity • Measures and observes the information numerically • Uses impartial approaches • Uses statistical procedures	• Gathers both qualitative and quantitative data • Develops an explanation for mixing • Integrates the data at different stages of inquiry • Presents visual pictures of the process in the study • Employs the practices of both quantitative and qualitative research

Table 13 Mixed method, quantitative and qualitative research approaches (Creswell, 2003)

3.1.3 Inductive or deductive research

The research may be categorised as deductive or inductive. Collis and Hussy (2013) describe the deductive research as a study in which a theoretical and conceptual structure is developed and then checked by experimental observations from which specific examples are concluded from the general assumptions, i.e. it is the movement from generalisation to particular. In contrast, inductive research makes conclusions based on observations of experimental reality and its movement is from specific to general.

3.1.4 Summary

Regarding this research, this research is considered as an applied and deductive research as the main aim of the research is to analyse the impact of SCM on residential housing construction projects performance, utilises the use of a qualitative and quantitative (mixed approach) as both data collection techniques were used. Furthermore, the purpose of the research is to explore more about the impact of SCM on housing construction projects performance which is classified as an exploratory research.

3.2 Simulation

This section discusses simulation in detail

3.2.1 Definitions

Simulation is known as the process of experimenting and testing the physical system of the mathematical computerised model (Chung, 2004). The physical system is explained as interacting chains of components that produce output and receives input. (Chung, 2004) Examples of this system include; bus and train transportation, shipping operations, logistics and distribution, etc. Some authors distinguish simulation as a dynamic, all-inclusive technique which produces a holistic representation, whilst evolving over time, of the output behaviour (Ammar and Mohieldin, 2002), and output can be determined according to its input variations (Halpin and Riggs, 1992). According to Law (2014), simulation is recognised due to its capabilities to study and examine, in detail, a real world system. Based on the research methods, simulation is considered as an instant experiment which is categorised as a quantitative research method (Yin, 2009).

According to the definition above, simulation is the method of studying and examining the system. In the real world, studying a system can be carried out in various ways. Law and Kelton (2000), as presented in figure 9.

Figure 9 Ways to study a system (Law and Kelton, 2003)

- Experiment with the actual system vs experiment with a model of the system. The experiment with the actual system could be chosen as the most desirable model when there is a possibility of changing the physical system during application of this model. However, it is seldom viable to apply this in reality because such an experiment would be too disruptive or too expensive for the system. Therefore, the model could be structured to represent the actual system and analysed as an alternative.
- Physical model vs mathematical model. The physical model could be: a cockpit that is used for pilot training, clay models that are used during a car's design process, the architectural physical models that are used to represent the real design. In another words, the physical model can be defined as the model that could be physically touched or seen. Unlike the physical model, the mathematical model can be defined as "a system in terms of qualitative and

logical relationships that could be altered and adjusted to understand how the model would react and subsequently measure the reaction of the system".

- Analytical solution vs simulation. Where the mathematical model would be available, the solution can be delivered through the simulation or the analytical solution. If the model is not complicated and simple enough, an analytical solution could be more valid than any other solution but, at the same time some models might be too complex and thus obtaining mathematical models that are valid can be too complex to be analytically solved. The model should be analysed and studied using simulation in this case. The simulation model therefore can be explained as "exercising the model numerically through the inputs in order observe their effect on the output's performance measures".

3.2.2 Advantages and uses of simulation

Back in the old days, simulation was used mainly for the military services and was achieved through evaluating the maintenance policies and by testing the large scale war games. However, simulation has grown dramatically in recent years and different examples of simulation are used for different purposes nowadays, as it shown in table 14 below.

Application area	Examples explain the usability of the simulation
Transport	• Air traffic control • Airport management • Traffic movement in the UK-France channel tunnel • Movement of crude and refined oil around the world
Manufacturing	• Material handling • Design of manufacturing plant and systems • Ship building
Health care	• Allocation of antibiotics and vaccines for emergency plans as a precaution in the event of any terrorist attack • Efficient and effective movement of equipment and goods in large hospitals • Emergency plan for emptying patients from the hospitals in particular circumstances
Business Process Reengineering (BPR)	• Simulation of office processes to obtain the target performance level • BPR in the UK financial service industry
Defence	• Battle simulations • Logistic operations

Table 14 Examples of application of simulation; adopted from Pidd (2013).

According to Chung (2004) Many benefits of using simulations exist as described below:

1. Obtaining an understanding of the system's process. As occasionally the system will be too complicated, the difficulty to comprehend the system's operation and the interference within the system by testing the individual components in isolation can be problematic, without relying on the use of simulation.

2. Establishing resource and operating policies in order to develop system performance. Simulation is beneficial for improving and developing existing systems in addition to allowing a comprehensive understanding of a system i.e. by revising operating policies, such as revising the priority's policies for the work orders, or resource policies, such as evaluating staff and setting break schedules.

3. Testing/checking the new concepts before implementing the new system. Prior to implementing or adopting a new system, simulation will provide an insight into the system. Modelling a new system is inexpensive when compared with procurement costs for equipment in a new system. Furthermore, an evaluation can be made when using the simulation model regarding the effects of different stages, configurations and expenses of equipment.

4. Obtaining information whilst not disrupting the actual system. Systems can be sensitive and critical therefore, it can be too difficult to apply any changes to these kinds of systems. For instance, it is not recommended to experiment with the operation policy on a checkpoint at a commercial airport, as that may reduce the effectiveness and the capabilities of the operational policy. Simulation model will make such an experiment very adaptable and effective if it is used on the same described system.

5. Experimentation in limited timeframe. The usability of the computers allows simulation experiments to be carried out in compressed time. Furthermore, in order to increase the analysis validity, multiple simulation replications can be applied easily.

6. Reduction in analytical requirements. Where simulation is not used, use of an analytical tool is recommended. This will only provide a constant approach at a specific time to analyse a basic system. In contrast, the simulation will allow the system to be analysed in real time during the simulation runs. Plus, the new simulation packages software has allowed the users from different backgrounds to study and analyse the system. All of that has subsequently led to analyse more systems than was possible previously.

7. Simply displayed models. Using animation, the model can be easily and dramatically displayed. In addition, animation can simply display the reaction of the model to other simulations in different circumstances at the same time, which will increase the credibility of the model. Observing the pitfalls in the system can also be monitored and fixed during the animation process.

3.2.3 Simulation and systems categorisation

According to Law (2014), continuous event systems and discrete event systems are categories that systems can be classified to. A discrete event system is a system with discrete status that changes by events that happens at separate times. As an example, a bank can be a good example of a discrete even system as the clients' number in a bank changes when the client arrives or been served. On the other hand, continuous event systems are systems that have variables which keep changing with respect to time. A moving plane can be an example of that system. (Law, 2014).

3.2.4 Simulation study process steps

In order to understand a simulation study, all of the simulation process steps need to be clear and comprehensive. According to Law and Kelton (2003), there are ten steps in a simulation study. Although, the simulation steps were conducted in a manufacturing context, it is probably relevant in the construction context. Each step of the simulation process is explained as follows:

1. Problem formulation and study plan: the first step is concerned with defining the objectives of the study, the appropriate questions, the simulation model to be used, the scope of the study, time frame, the performance measurements and required study resources.

2. Data collection and model definition: the second step focuses on data collection. The data here is about the systems layout, information related to parameters specifications and other operating procedures. All of the information gathered here will be summarized in the assumption document which sums up all of the hypothesis and assumptions taken in a simulation study. This is known as the conceptual model as well.

3. Conceptual model validation: the main aim of this step is to make sure that the assumptions made in the previous step are all valid and correct before the simulation begins.

4. Computer program construction and verification: this step is concerned with programming the model or using simulation software and debugging the simulation program. Verification techniques will be described in detail in the next chapter.

5. Pilot runs: the use of pilot runs is carried out for validation purposes.

6. Program model validation: a comparison between the established model and the existing one is carried out here in order to check the validity of the simulation. The results of that comparison need to be reviewed and analysed in order to check the impact of the different model factors on the performance parameters.

7. Design experiment: this step is concerned with issues related to the amount of random checks, its length and the amount of different factors used in the simulation.

8. Production runs: this step is about producing data by running the simulation software.

9. Data analysis: the data gathered in the previous step is analysed and reviewed here to help in the decision-making process.

10. Results presentation: this step’s main objective is to present the results from the simulation process. The assumptions, parameters, performance measurements and other factors will be presented. Some of the presentation will be taken from step 2 and the remainder will be from the other steps. Data presentation can be done using many techniques such as: animation and visualisation techniques.

Presented in figure 10 on the following page is the steps in a simulation process.

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Figure 10 Steps in a simulation process (Law and Kelton, 2003)

3.3 The adopted research tools

Preliminary investigations, survey and simulation models were adopted in order to finalise the aims and objectives of this research, as figure 11 presents.

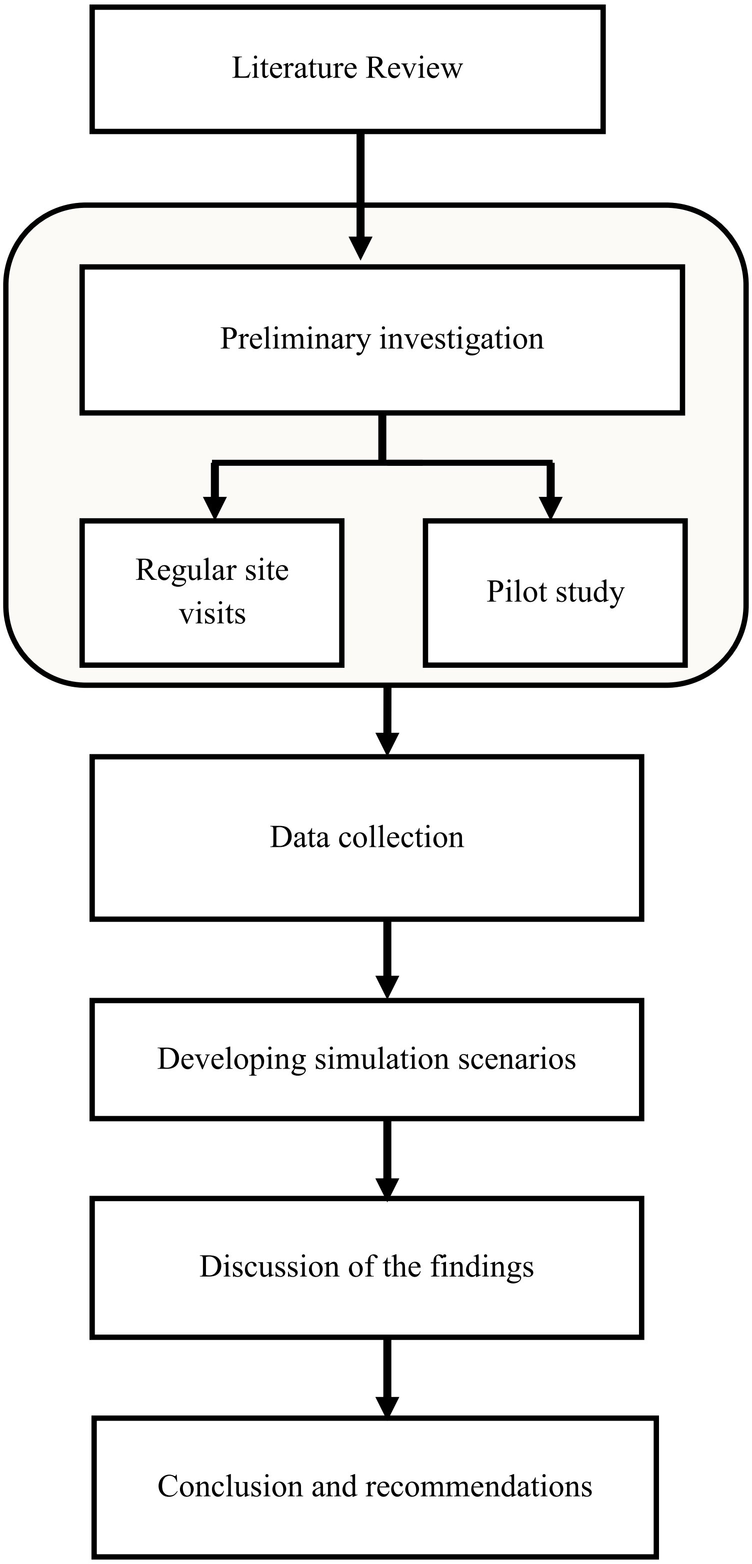


Figure 11 Adopted research tools

The preliminary investigations main aim was to obtain more knowledge and information regarding the practices of supply chain management in the construction industry. The preliminary investigations were divided into two stages. The first stage was reviewing supply chain management literature in the construction industry, its flows, practices, importance and problems. The second stage was by visiting two medium sized residential housing projects for two months on a regular basis in Amman/Jordan to observe SCM in practice. The main aim of this stage was to understand and point out supply chain practises on construction projects in a real life scenario. Moreover, this stage helped in identifying site managers, supervisors and decision maker's awareness of the importance of SCM furthermore, the extent of impact on projects performance.

The survey was conducted in order to collect data to be used in developing various simulation scenarios. The development process of the questionnaires relied on the preliminary investigation and literature review. The questionnaire consisted of four sections, each section was related to a flow in the construction supply chain. Each section contained questions about the relevant flow, difficulties within the flow in obtaining particular items and the probability of that difficulty occurring; i.e. within the labour flow, what profession causes difficulties? What's the probability of that to occur?

The simulation process consisted of a general critical path method (CPM) network of the skeleton level of a typical medium residential housing project, which was obtained from one of the projects that was visited, and the varying supply chain delays which were pointed out from the survey. Chapter 5 explains the simulation process in more details

The simulation was very helpful in applying different supply chain practices, concerns to be applied during the simulation process therefore it will help when studying the impacts of supply chain management on construction projects performance in isolation of any other factors that may have an impact on the project's performance. Moreover, as stated previously, O'Brien, Formoso, Vrijhoef and London (2009), mentioned that simulation is a reputable and proven type of analysis in construction management and construction engineering.

O'Brien, Formoso, Vrijhoef and London (2009) discussed in more detail, Law and Kelton (1991) findings, about simulation dimensions which are as follows:

1. Dynamic vs. static: dynamic simulation is a representation of a system whilst it develops overtime whereas, static simulation represents a situation at a particular time.

2. Stochastic vs. deterministic: the absence of random components defines the model deterministic whereas, when the outcome contains random variables the result is stochastic.

3. Discreet vs. continuous: in discreet simulation the system variables differ only at particular points in time whereas, in continuous simulation events may occur at any given time.

O'Brien, Formoso, Vrijhoef and London (2009) highlighted the advantages of dynamic simulation which are:

1. Time impact is incorporated in the performance evaluation

2. Dynamic simulation is relatively flexible when compared to other analytical tools

3. Dynamic simulation enables the user to have control over further variables as oppose to the real system

This research utilised Microsoft Project 2007 software which represents dynamic simulation and is discussed in chapter 5.

The next section discusses in detail the adopted research tools. The simulation development process is discussed in the following chapter.

3.3.1 Research arrangement

Figure 12 next, illustrates the research organisation and execution, represented in a flowchart. The main tasks are in boxes and the detailed activities in each task are represented inside the corresponding main task. The tasks linked with each other are presented and linked by arrows. This data flow diagram represents all of the steps taken on each task in order to finalise the research aim and objectives. Detailed discussion about each task and activities are presented on the related chapter.

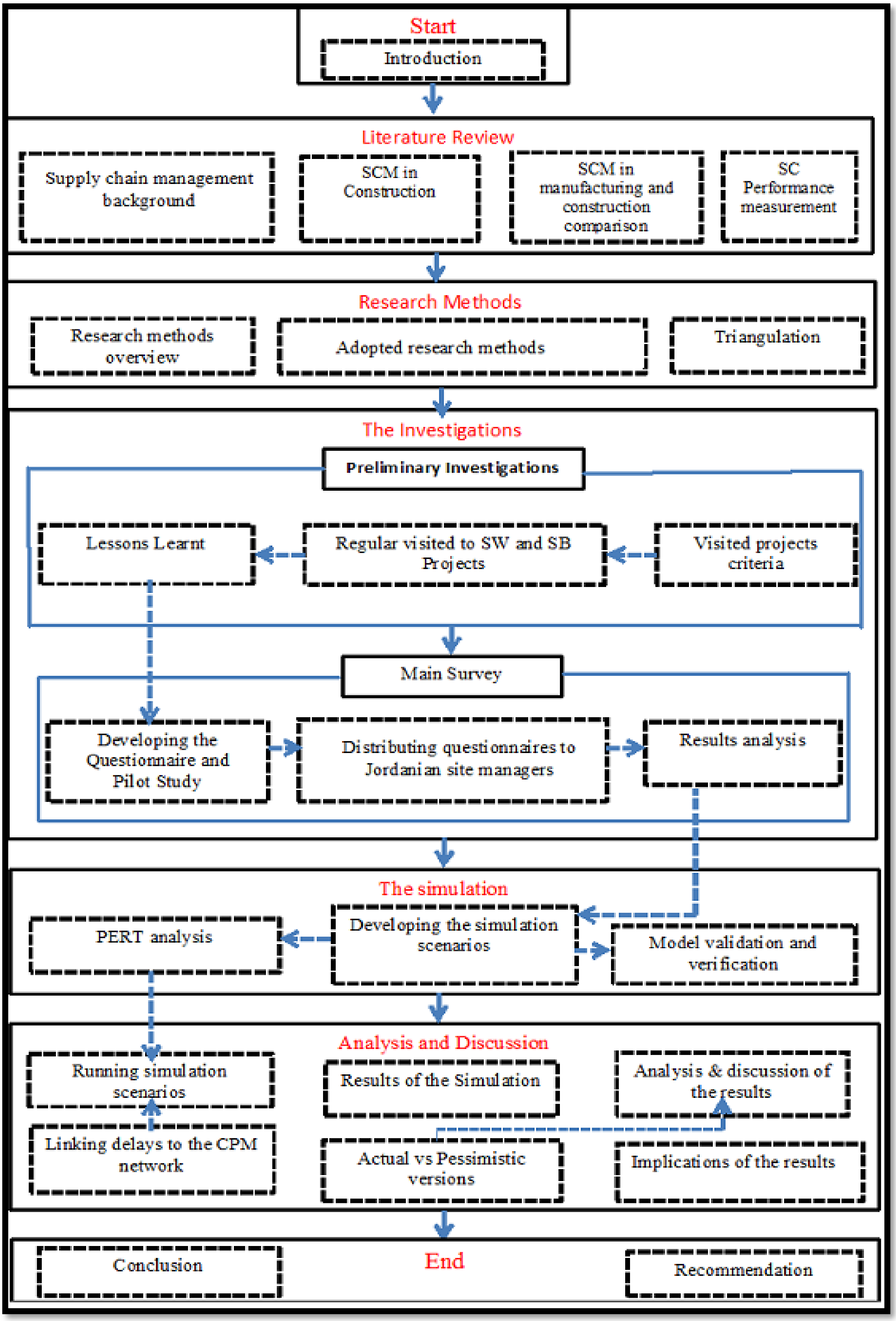


Figure 12 Research arrangement (DFD)

3.4 Preliminary investigations

3.4.1 Regular visits to residential construction sites

In order to link supply chain management concepts with real life scenarios and cases, regular visits to, small to medium residential construction sites were carried out. Two construction sites were visited over a period of two months in Amman, the capital of Jordan. the sites visited and the duration of the visits were selected based on the availability from both the researcher and the contractors. For this research purposes, the main aim of the visits was to help the researcher in observing SC practices on construction projects and all the barriers, issues and concerns related so 2 medium residential housing projects were sufficient to meet the aim of the visits.

The two residential housing projects sample were chosen based on O'Brien (2009) criteria as follows:

1- In order to allow the researcher to understand and identify the impacts of supply chain management on project performance, the project should be small.

2- Choosing a normal project is very important as if it was a special project that needs special fabrications and techniques, the results will not be able to be generalised.

3- The researcher needs to have access to the supply chain management and the general project data.

Residential housing projects in Jordan match O'Brien's criteria, as residential housing projects are normally small to medium sized, simple and general. The selected projects were chosen in Amman city for reasons related to time limitations and accessibility.

Moreover, to collect data from residential housing construction projects, sites visits were the main and most accurate means to gather data and to get an overview about the supply chain of each project. Visits took place twice a week for each project over a period of two months. The main aim of the visits was to gain a better understanding of supply chain management practices based on a real-life time scenario. The visits helped in exploring more about the supply chain problems, practices, limitations, and important issues related to the integration process.

3.4.2 The Survey

As stated earlier, the main aim of the survey was to collect the needed data to develop the simulation scenarios. Before establishing the questionnaire, it was necessary to make sure that the questionnaire was valid and would accomplish the aims and objectives it was set for. Conducting a pilot study helps in getting good feedback before establishing the survey. Moreover, in order to increase the amount of respondents, questionnaires were sent via emails to residential housing construction companies in Jordan targeting site managers. These companies were selected based on their high reputations and having over 10 years' experience within the industry in order to obtain more accurate data from reliable sources. Questionnaires were formulated and developed based on the data gathered from preliminary investigations and the literature review. The development of the main survey is discussed in the following chapter.

3.4.2.1 Pilot study

According to Haralambos (2008), a pilot study, also called as a pilot experiment is a preliminary small scale study that is conducted to examine the cost, effect size, time, feasibility and adverse events of the study in order to improve the study design and to predict the sample size.

For the above reasons, a pilot study was conducted. The pilot study consisted of 5 pages and all the questions were aiming to investigate the client-supplier relationship and how the construction supply chain elements act due to different factors and situations. The pilot study was circulated to reach 15 site managers. The amount of respondents was 4. Some site managers reported that some questions were highly confidential and cannot be answered. Others claimed that it required a lot of time and effort to answer the questions which they did not have.

3.4.2.2 Respondents

Questionnaires were directed to reach experienced site managers that have been working for a long time in residential housing projects. The reason for targeting site managers is their experience and comprehensive knowledge in residential housing projects. CEO's, directors and project manager's responses were also taken into consideration regarding their managerial roles that allow them to access all information regarding the different practices and steps in doing the project.

3.4.2.3 Questionnaires circulation

As mentioned earlier, questionnaires were sent via email in order to reach more people and obtain wide responses. Other techniques can be suitable such as: the provision of a self-addressed and stamped return envelope and a personalized cover letter. According to Dillman (2011), addressed personalised letters to certain individuals influence them to respond back and it increases the response probability. Deadlines were also set in order to encourage responses. All of the previous techniques were employed for this questionnaire and reminder emails were sent after 3 weeks in order to increase the number of respondents. Appendix A3 presents the steps in the questionnaire development process.

3.5 Triangulation

According to Collis and Hussey (2013), triangulation is concerned with using different research approaches, techniques and methods, all in the one study and is aimed at overcoming partiality that can happen from using a single research method. Denzin (1970) claims that triangulation leads to further reliability and validity than a single research method. Moreover, Easterby-Smith et al. (1991) declared that there are different types of triangulation, which are: investigator triangulation, triangulation of theories, data triangulation and methodological triangulation. The following, table 15, summarises the different types of triangulation.

Triangulation	Description
Investigator triangulation	Data was collected and results were compared independently by different researchers on the same phenomenon
Triangulation of theories	To illustrate a phenomenon in a discipline by the use of a theory of another discipline
Data triangulation	Data is collected from different sources or at different times
Methodological triangulation	Qualitative and quantitative methods of data collection are used

Table 15 Types of triangulation (Easterby-Smith et al. (1991)

Regarding this research and according to the different types of triangulation described above, this research will maintain methodological triangulation and data triangulation together. The reason being is the use of qualitative and quantitative data collection methods and data was gathered from different residential construction sites. Regarding the data triangulation, gathering data from various residential housing construction projects enriches, widens, and strengthens the set of the data that is gathered. Moreover, gathering data from different sites was aiming to avoid the bias that might happen from collecting the data from a single source.

On the other hand, the use of the methodological triangulation type was clear and can be seen by looking at the use of qualitative and quantitative methods at different stages of the investigation. During the preliminary investigation, regular visits to residential housing construction sites presented both qualitative and quantitative data. Moreover, quantitative data was also obtained from the main survey which was completed by the respondents.

In addition, the use of the simulation method aimed at representing a real life scenario thus, helping to generalise the impacts of supply chain management on construction projects performance, determining to what extent supply chain management can impact project performance in terms of time and increasing the robustness of the research.

3.6 Summary

This chapter discussed research methodologies, types, designs and data collection techniques. Based on the discussions above, the needs of the research inform the design of the research methodology to incorporate the use of qualitative and quantitative mixed approach in the data collection process as the data gathered from the preliminary investigation is an example of the qualitative method and the main survey is an example of the quantitative method. Using a mixed approach allowed the development of the simulation scenarios to fulfil the research objectives.

Chapter 4

Discussion of preliminary investigation and the main survey

This chapter discusses in detail the investigations that were conducted for the research. As mentioned previously, the research obtained information by way of preliminary investigation and the main survey. The chapter consists of two sections:

4.1 Preliminary investigation: this section discusses the preliminary investigation that was carried out in detail. The section consists of a discussion regarding the regular visits that was conducted at residential construction projects, the challenges and problems that were identified and lessons learned.

4.2 The main survey: this section describes the questionnaire, its design and presents the results.

4.1 Preliminary investigations

4.1.1 Jordanian construction industry background

According to Bank Audi (2015), the Jordanian construction industry represents 5% of the Gross Domestic Product (GDP). Al-Rifai and Amoudi (2015) stated that the construction industry in Jordan is divided into two categories:

1- Large companies which are companies that tender for and/or undertake multimillion dollar projects.
2- Small and medium companies, usually family owned and directed by the owner.

The construction industry in Jordan suffers from several problems as a result of many factors including: the construction supply chain and financial issues. According to Al-Momani (2000) delays in the construction industry are the result of poor design, changes in design, Weather, unforeseen site conditions and late deliveries. On the other hand, Sweis, Sweis, Abu Hammad and Shboul (2007) stated that the main sources of construction projects time delay in Jordan are due to the following:

1- Internal environment within the contractor’s company: information flow and finance.
2- Material shortage: cement, concrete, sand, bricks etc.
3- Labour shortage: unskilled, semi-skilled and skilled labours.

4.1.1 Regular site visits

From May 2014 until July 2014 site visits were conducted at two residential housing projects, both of which were located in Amman, Jordan. The construction work was being carried out by two independent contractors. Both contractors are small to medium sized companies that have been in the industry for more than 20 years, specialised in residential housing. Company X is a Jordanian-based construction company, which is engaged in the construction and development of residential flats, commercial premises and industrial galas. The Company develops and sells properties on an outright basis, except in the case of old buildings taken up for conversion. The Company undertakes projects either on its own, in partnership with the seller of the land, or as a joint venture with another construction company. On the other hand, Company A is a Jordanian-based construction company as well that is specialised in the construction of residential housing projects, Drainage and site works for residential, industrial and commercial building developments

The main aim of the construction site visits was to obtain a better understanding of the practice of supply chain management. Preliminary investigations indicated that predominantly, construction projects usually use subcontractors and suppliers, this is not the case in civil engineering projects, due to the fact that building projects involve more specialised works and require a broad range of materials. As a result of the preliminary investigations it became apparent that investigating issues relating to the supply chain on building projects, as oppose to the issues on civil engineering sites, would give more insight. The selection for residential building projects specifically, was due to the fact that these types of projects are usually of medium size, not over complicated and are very common (4 floors, 8 apartments in total), which allows the practice of SCM and the extent of impact on projects performance to be more easily recognised and understood.

Regular site visits enabled identification of particular types of problems and delays in relation to the practice of supply chain management. Key factors were identified during visits by way of direct observations, examining project documents and attendance at project meetings. This level of involvement in the projects allowed for the learning process to be achieved by highlighting real life situations which, in turn, helped to understand how issues within the supply chain can and do have an impact on project performance. Whilst visiting one project during this study an offshoot was obtained, namely a specific CPM network which became the basis of the generic critical path method network used later in developing the simulation scenarios. Visits to each project are described in the following sections. As the characteristics of each project are unique, available data and lessons learned were at times exclusive, therefore may not always be generalised.

4.1.1.1 SW Project-1

- **Short description of the project**

Located in Amman, this was a residential housing project with a budget of approximately 1 million JD (about 1.41million US dollars). The project was planned for 12 months, starting 1st May 2014 until 1st June 2015. One of the main medium sized construction companies in Jordan was appointed as the main contractor, 'X'. No work was directly carried out by the main contractor; neither did they employ a workforce. The main contractor subcontracted out the work in packages to 5 subcontractors. The subcontractors were responsible to both complete the work and manage their own suppliers and sub-subcontractors.

- **Lessons learned from the SW project**
    - Information distribution and coordination meetings
    - Information flow problems
    - Material delivery
    - Delays identified in the project
    - Client design changes

The above lessons are discussed below.

Information distribution and coordination meetings

On the SW project two types of meetings took place regularly, displayed in table 16. Through these meetings information could be both communicated and managed along the supply chain. An upstream organisation, that is the client or design team, was able to pass information or discuss and resolve any problems in relation to the project to downstream organisations, suppliers, subcontractors and indeed vice versa. Strategically, to both manage and communicate necessary information to the appropriate organisations the main contractor was ultimately in the most advantageous position. The progress of the project and whether it was on schedule could also be monitored by the client at the meetings, by way of the main contractor's report and the weekly reports given to the main contractor by the subcontractor on a weekly basis.

Type of meeting	Required by	Attendance	Frequency per month
Site	• Client	• Client • Designers • Contractor	• Once
General work information	• Contractor	• Designers • Contractor	• Twice

Table 16 SW meetings

Problems related to information flow

Particular information was required prior to the commencement of a project activity such as; specifications, permission permits, drawings, etc. This information was recorded and managed on the 'required information schedule' form. According to the schedule, updated 14th May 2014, there were 296 information requests, of which 38 were delayed. This amounts to 13% of information requests being received later than scheduled. The delay in the required information being obtained ranged from 4 days to 18 weeks even though the information was requested 2 to 22 weeks before being required. In addition to the above, some information provided was incomplete when received.

One instance of an issue relating to breakdown in information distribution arose when a subcontractor who was entirely responsible for electrical works, had begun to both order materials and commence with the project as he had dealt directly with the designer and obtained drawings without any instruction from the main contractor. The main contractor was not in receipt of the drawings at that point in time and it turned out that the drawings had been modified with a design change. Consequently, the materials that the subcontractor had ordered and part of the work that had already been carried out was not of any use and was wasted. Subsequently, it was the subcontractor that was ultimately responsible for the rework and all relating costs; the main contractor insisted he was not liable as the subcontractor had not followed the correct procedure.

Material deliveries

A policy was set in place which prohibited materials being delivered at certain times. Deliveries were only allowed outside the following times: 08:00-12:00 and 13:00-18:00. The main reason for setting these times was in order to not disturb the surrounding area as there is a nursery, a hospital and a school therefore, delivering materials at random times may cause traffic congestions and blocks the main entrance of the hospital. This policy was stipulated to the subcontractors however, on occasions materials had been delivered during these times. Consequently, a formal complaint was issued to the related organisations by the main contractor where an infringement had occurred.

Delays identified in the project

Identified delays in the project were gathered during site visits. 40% of the total delays were in relation to supply chain issues but, unlike weather delays, totalling 60%, actual hours lost due to those delays could not be established therefore, making it more difficult to quantify them although their impact was obvious.

As can be seen according to the main contractor's record, the majority of the delay's in relation to supply chain issues were those associated with subcontractors, specifically poor progress. Issues subcontractors faced were those such as not being able to start on schedule or having to stop once work had commenced. This was due to other subcontractors not completing their work to schedule or the site not being prepared. In order to avoid further delays in the project, the main contractor would, where possible, re-sequence the work.

It should be noted; it seemed that there are only a few types of delays which give an indication that the project's progress is apparently going well. However, other delays may not have been identified by the main contractor due to the fact that all works were subcontracted and many of the delays which may have occurred were dealt with at the subcontractor level. This would result in the delay not being identified or recorded by the main contractor. Following in table 17 is a list of identified delays.

Date	Delay	Delay type
5th May 2014	Rain	Weather
8th May 2014	Rain	Weather
10th May 2014	Labour shortage	Supply chain related
23rd May 2014	Rain	Weather
1st June 2014	Insufficient amount of bricks	Supply chain related

Table 17 SW delays identification

Client design changes

One month after the project commenced the client requested a change to the specification of the kitchen, requesting the kitchen to be built one metre longer than the original plans. The impact on the project was significant as the request would not only bring the project to a 'stop' but, rework needed to be accounted for. This included issues relating to planning permissions, architectural designs, material, labour and indeed costs. As discussed in the literature review chapter, client's involvement in the project is considered as an information flow whereas, information flows within the main contractor's company are considered as management information flows.

4.1.1.2 SB Project-2

- **Brief project description**

Located in the north of Amman. This was a residential housing project with a budget of approximately 1.5 million JD (about 2.12 million US dollars). The project was planned for 11 months, starting May 2014 until April 2015 and 'A' company was appointed as the main contractor. There were 6 subcontractors hired, covering approximately 50% of the work, some of which were nominated by the client. There were also 7 suppliers involved.

- **Lessons learnt from SB project.**

Lessons learnt were as follows:

- ✓ Coordination meetings
- ✓ Procuring meetings and delivery times
- ✓ Delivery of incorrect material specifications
- ✓ Delays identified in the project

The above lessons are discussed in more detail below.

Coordination meetings

As in the SW project, two kinds of meetings were held regularly on the SB project, displayed in table 18. Through these meetings information could be both communicated and managed along the supply chain by upstream organisations being able to pass information or discuss and resolve any problems in relation to the project to downstream organisations and indeed vice versa. Tracking the project's progress was also a function of the meeting.

Type of meeting	Required by	Attendance	Frequency per month
Progress	• Client	• Client • Contractor • Project manager	• Once
Contractor review	• Contractor	• Project manager • Designer • Site manager	• Four

Table 18 SW project meetings summary

Procuring materials and delivery times

The material procurement cycle starts when the financial manager receives requisition forms from the site manager and then the relevant supplier is forwarded the purchase order. A copy is also sent, by the financial manager, back to site on the next working day. Suppliers then send the materials to site within hours in response directly to the financial. Materials ordered can be delivered either, all at once or as and when required on site however, where necessary, the site manager can order urgent material needs from the supplier directly.

The lead time, which is the time from placing a materials order to the time the materials are delivered on site, was considered as an important factor. Standard materials are normally available and could be obtained from suppliers within the same day whilst other materials could have a lead time of weeks to procure which resulted in material lead times ranging from 3 days to 6 weeks.

A 'materials required schedule' was unavailable for this project. Instead, the site manager relied on his 10 years of experience to know when to place a materials order and the time it will take for that order to be delivered. According to the site manager a 'materials required schedule' was not needed due to the scale of the project, this was also agreed by the contract manager. Delivery times for this project were also only at particular times, i.e. 10:00-12:00, for safety reasons and in order to avoid disruptions to the neighbourhood.

Delivery of incorrect material specification

The delivery of the incorrect specification of drainage pipes was the cause of a delay. This was, in particular, regarding the quality of the pipes. As the pipes did not meet the specified standard for the project they needed to be replaced which caused a 3-day delay, 1-day to order and 2-days' delivery, on the initial phase. This delay impacted on other areas of the project as ground workers could not continue without the correct pipes and waiting time regarding excavators.

Delays identified in the project

Identified delays in the project were related to information, labours, materials and equipment flows. The information in relation to these delays was identified during site visits from 7th May 2014 to 1st June 2014, gathered from the site diary as follows: 65% of the delays were caused by supply chain issues and 35% were the result of natural causes. Specific hours lost by either of the causes failed to be recorded in the diary. According to the site manager, these delays did not cause a significant impact on the overall project as they mostly affected non critical activities. In addition, reassignment sources or re-scheduling activities were carried out in order to diminish the delay's impact on the project.

Date	Delay	Delay type
7th may 2014	Heavy rain	Weather
25th may 2014	Design change from client	Supply chain related
7th June 2014	Hammer break down	Supply chain related
14th June 2014	Bricklayers shortage	Supply chain related
26th June 2014	Incorrect specification of bricks	Supply chain related

Table 19 SB delays identification

The main issues relating to delays cause from subcontractors are as follows:

- ✓ Labour associated delays
- ✓ Obtaining client related information
- ✓ Subcontracted work
- ✓ Equipment
- ✓ Materials

- **Labour associated delays**

Above, several examples can be found where there was insufficient labour/manpower or no skilled labour available at all. Delays were caused in this project by various skills such as: tilers, labourers, painters etc. On occasions, tilers did not attend this project for several days as they were completing works on other projects, indicating tiling is a highly demanded skill.

- **Delays in obtaining client related information**

The project was initially delayed by several days due to the fact that the client wanted to make a change in the project's design. This change in design resulted in delaying the project's activities whilst waiting for the modified design from the client. This in turn delayed the placing of a materials order, hence delaying the job. Examples of further delays by the client are as follows:

1. Main contractor had to stop working for 4 weeks while the client contemplated modifications to the design and specifications.
2. Extra work to be carried out as a result of the modified design.

The design change from the client resulted in another delay. The site manager had not been made aware that the client and the designer were making some changes to the design and therefore, did not factor this in. Consequently, the site manager needed to reorder the sequence of some of the work to be carried out and distribute some labourers in order to demolish initially completed work. This completed work had been carried out during the time when the manager was unaware of these design changes.

- **Delays associated with subcontractor's work**

Poor performance by subcontractors was a significant factor in disruptions. At times, their lack of progress was the cause of disruption to other trades. Electric wires were all over the site as the electrician stated, on a telephone call, that he was not sure if the wires are needed later on or not. Upon return after several days' absence, the electrician carried on with other activities on site without giving any concern with regards to the wires. According to the site manager, he understood that other works had to be carried out on other projects by the subcontractors although he stated that working in this manner puts other trades at risk and is highly inefficient. In order to meet the schedule subcontractors were at times forced to work 7 days a week so they can finish on time and avoid penalties. However, on one occasion, the subcontractor was issued a note by the main contractor outlining the subcontractor's inability to advance site works which resulted in delaying other trades. Consequently, the subcontractor was penalised and was made to pay any claims as a result of that delay.

- **Delays associated with plant**

One delay only occurred in this project in relation to plant or equipment flow. A hammer stopped working suddenly, and it took the hiring company 2 days to send a mechanic to make repairs, this resulted in 2 days of delay and the occupied space of the hammer caused additional delays as the space was not available for unloading material deliveries.

- **Delays associated with materials**

Some delays regarding materials were identified in this project although for the most part materials arrived according to schedule. Delays such as: wrong material specifications, damaged material and late delivery were among the issues. Missing window components contributed to delays and the delay in actual installation of the windows and doors had a knock on effect contributing to the delays. Although suppliers were the usual cause of delay with regards to late material delivery, delays could also arise as a result of information being received late from the client/architect, resulting in delays in orders being placed, as was the situation mentioned previously regarding the design changes.

On one occasion some cement was stolen from site by the careless handling of one of the site guards. This resulted in a one-day delay in order to receive a replacement order.

The above section described the lessons learned though visits to the SB project which provided a way to experience real life situations and issues which arise on site in relation to supply chain management. Lessons learnt are used in the development of the questionnaire in the main survey; discussed in the following section.

4.2 The main survey

The main survey was the final piece of the investigation and its purpose was to incorporate the collected data into the process of developing the simulation scenarios. The data for the main survey was gathered by way of questionnaires being distributed to various contractors, whom specialised in building projects, throughout Jordan. Details of the various stages of development and testing the questionnaire, together with the results, are described next.

4.2.1 Questionnaire development

The initial step in the development of the questionnaire was to establish a list of all potential delays that may affect construction projects using input data gathered from both the preliminary investigations and literature review, as per appendix (A1). Included in the list of delays are instances established from preliminary investigations. Problems such as finance, materials, site conditions, nature and so on can all be contributing factors to the delay in various aspects of a project. Likewise, delays may be looked at from the point of view of who is responsible for them such as; subcontractors, suppliers or the client.

As some delays were both overlapped and duplicated in the initial list, it was therefore necessary to remove them. This process simplified the list, making it clearer in order to avoid confusion, as per appendix (A2). As not all delays remaining in the list had any relevance regarding issues in relation to the supply chain it was necessary to simplify the list further, hence those issues were removed.

The remainder of the supply chain delays may take place either prior to the start of the project or during the construction period and can be seen from the time of occurrence perspective. As only delays occurring during the construction period are covered in the simulation model delays prior to the projects commencement are ignored. Delays can be further narrowed down to those which occur before a particular activity, preventing the activity starting on time and those which occur during the project activity, hence extending the duration of the activity. The next step therefore was to identify which delay impacted the activity start date and which impacted the duration of the activity.

As the data gathered in the questionnaire was for simulation purposes, that is, what is the possibility of a situation taking place and to what extent if it does occur, the delays must be able to be operationalised, meaning, it must be possible to know the probability of an event occurring and its extent if it does so. However, identifying whether a delay could be operationalised in reality can prove to be very difficult. For example, one supply chain issue is poor material planning, which inevitably causes delays but, the problem in trying to operationalise such an issue is that it is difficult to establish the probability of such an event or the extent of impact should it occur. For this reason, this particular delay together with those delays which were unable to be operationalised were also removed from the list as these delays could in actual fact be a proportion of other delays i.e. ‘difficulty in sourcing materials’ may incorporate poor material planning.

Based on flows identified in the construction supply chain, the delays remaining that could be operationalised were then assigned to five categories namely; equipment/plant/temporary work flow, material flow, work flow, labour flow and information flow.

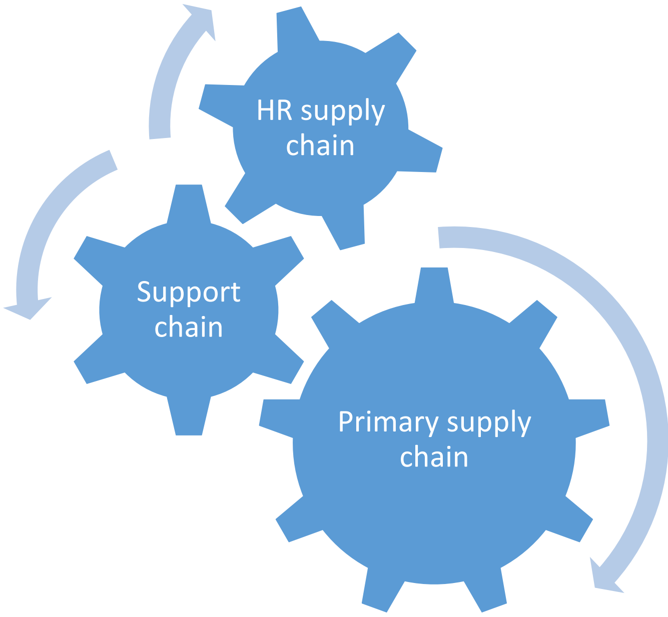


Figure 13 Categorisation of construction supply chain flows (Muya et al. (1999)

According to Muya et al. (1999) three of the above flows presented in figure13 have been adopted from the categorisation of construction supply chain. The same author specified that there are three construction supply chain types; the primary supply chain, the support chain and the human resource supply chain. The primary supply chain provides components, raw materials, sub-assemblies plus mechanical and electrical equipment, all of which are materials incorporated into the final construction product. Expertise, equipment and materials such as; excavation supports, scaffolding, false-work and framework, site access and temporary works in relation to the operation of equipment, facilitate construction are provided by the supply chain. Inputs of labour and supervisory staff are provided by the human resource supply chain. In conclusion, the construction supply chain incorporates the following flows; materials, plant/equipment and labour.

As well as the above three flows, the remaining delays could be considered as management flow delays and information flow delays. Information delays for this research will be the delays caused by the client and management delays are the delays that were caused because of the main contractor's management information flow. Figure 14 illustrates the construction supply chain flows that are analysed in this research.

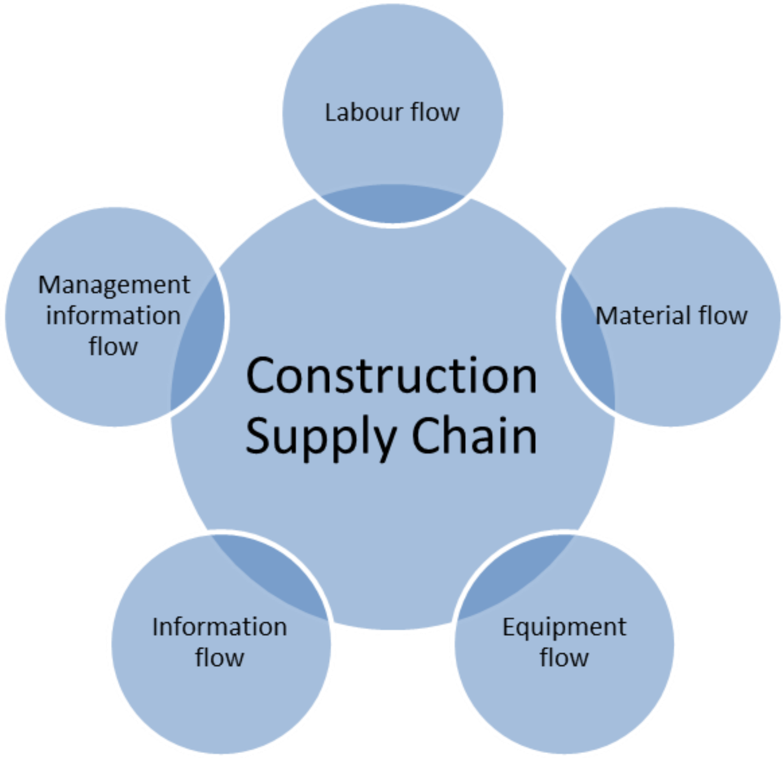


Figure 14 Construction supply chain flows

In order to obtain a broad coverage and extensive feedback the questionnaire was designed in a semi-open manner (semi structured). This was to enable the respondents to respond with a certain degree of freedom as oppose to a closed-type questionnaire which limits the answers usually to two choices i.e. yes/no. In addition to the optional answers available on the questionnaire respondents were also able to answer using the blank spaces provided.

In order to assess the respondents when responding, it was pointed out that a typical residential housing project was being referred to in the questionnaire. Identification of specific delays were asked, which were likely to occur on site in the construction supply chain i.e. do you face labour shortages during construction, if so, what is the profession and what is the probability of this happening, and so on. Secondly, respondents were required to give an indication of the frequency of the delays in percentage terms. This information represents the probability of occurrence and indicates the extent of the impact should it occur. Three values represent the extent of impact; maximum, most likely and minimum, in order to be used in developing the simulation scenarios. For full questionnaire with cover letter see appendix (A3). Next are examples of conventional questions asked in the questionnaire:

- Were materials delivered on schedule, if not, which material?
- How frequent is the occurrence?

- When materials were delayed, what was there estimated duration? (Minimum, most likely, maximum)

4.2.2 Questionnaire testing

To examine whether the questions within the questionnaire were formulated correctly, clear and answerable by the respondents, a pilot questionnaire was circulated to 15 site managers, 4 responded, that had at least 10 years of experience within the construction industry in Jordan and each one of them works for different contractor. The managers were from different companies and had experience specifically in residential housing projects; therefore, they were considered particularly suitable to test the questionnaire. Feedback from the managers indicated that the questions could be answered and were reasonably clear, although as was expected, not too easily. They proposed some minor alterations in terms of wording but overall considered the questionnaire workable and clear.

4.2.3 Survey results

The survey results are presented in tables 20, 21, 22, 23, and 24. The following figure 15, summarises the average probability of supply chain delays occurrence. As stated before, information flow refers to the information from the client and the management information flow is the information flow in the contractor company and suppliers. Moreover, all supply chain delays refer to the probability of work delays to happen resulting from the construction supply chain.

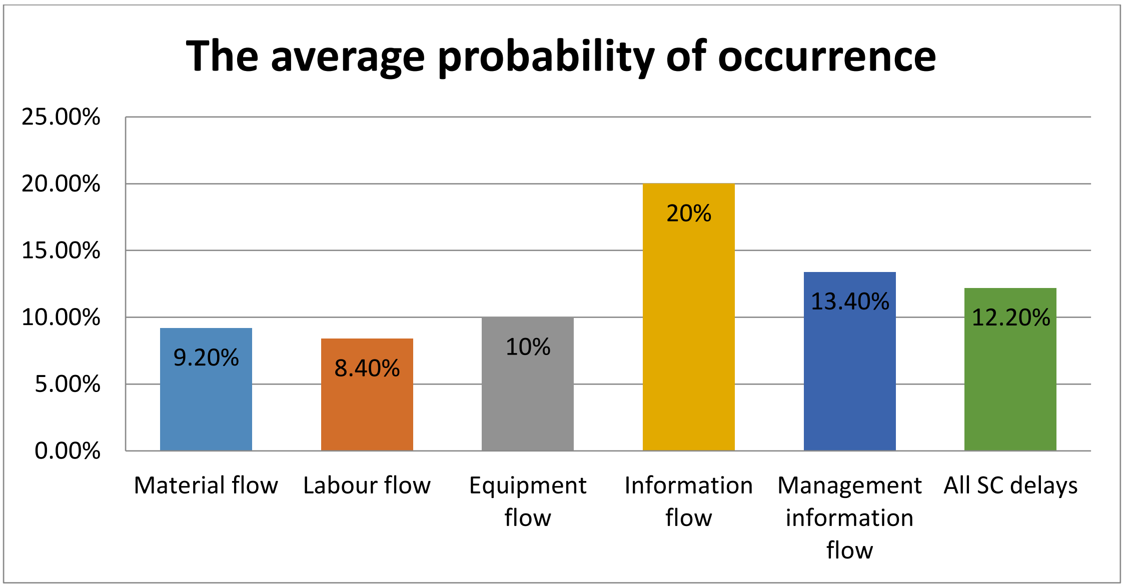


Figure 15 Average probability of supply chain delay occurrence

Material flow														
Material delivered later than scheduled delivery dates	**Percentage of material delivery delays**	**Delay on start day**			**Material delivered with wrong specification**	**Percentage of material delivery delays**	**Delay on duration day**			**Material damaged on arrival**	**Percentage of material delivery delays**	**Delay on start day**		
		Min	Most	Max			Min	Most	Max			Min	Most	Max
Concrete	10%	3	6	9	**Concrete**	19%	1	2	8	**Timber**	4%	2	5	8
Steel Reinforcements	7%	2	4	7	**Steel Reinforcements**	10%	2	5	9	**Bricks**	9%	1	2	3
Sand	10%	3	6	9	**Bricks**	7%	5	9	10	**Drainage**	6%	1	1.5	1.5
Bricks	8%	2	5	8	**Timber**	15%	4	6	8	**Tools**	5%	1	2	3
Scaffolding	16%	0.5	1	2	**Drainage**	4%	0.5	1	2	**Steel**	8%	4	6	12

Table 20 Material flow delays

Information flow				
Information	**Percentage**	**Delay**		
		Min	Most	Max
Payment	36%	0.5	1	1
Weekly Reports	4%	1	1	2

Table 21 Information flow delays

Equipment flow				
Equipment	**Percentage**	**Delay**		
		Min	Most	Max
Hammer	11%	2	6	12
Crane	9%	1	4	6

Table 22 Equipment flow delays

Labour flow				
Skill shortage	**Percentage**	**Delay**		
		Min	Most	Max
Electricians	9%	1	2	3
Plumbers	6%	1	1	2
Ground workers	16.4%	0.5	1	2
Surveyors	8.4%	1	3	4
Joiners	8%	1	1	5
Labourers	2.4%	1	2	3
Bricklayers	7%	1	2	3
Scaffolders	9%	4	5	7
Excavator and frame builders	8%	1	2	4
Compaction labourers	11%	4	8	9
Steel workers	7.4%	3	6	7

Table 24 Labour flow delays

Management information flow				
Affected activities	**Percentage**	**Delay**		
		Min	Most	Max
Project documentation	24.9%	3	4	6
Objectives review	5%	0.5	1	1.5
Achievement objective	2%	0.5	1	1.5
Quality	15%	1	2	3.5
Client acceptance doc	20%	0.5	0.5	0.5
Phase review	13.5%	1	2	5

Table 23 Management information flow delays

4.2.3.1 Survey responses

In early May 2014, 132 questionnaires were distributed and 22% responded. Although site managers were the targeted respondents, the actual respondents varied as follows: 53% Site Managers, 30% Project Managers, 13% Quantity Surveyors, 4% Building Managers, see figure 16 below. Furthermore, the majority of the respondents specified they have had an involvement within the construction industry for many years, the average being 18 years. Taking all of the above into consideration it would be reasonable to assume that the information gathered was reliable as the respondents had good knowledge and good understanding of the industry.

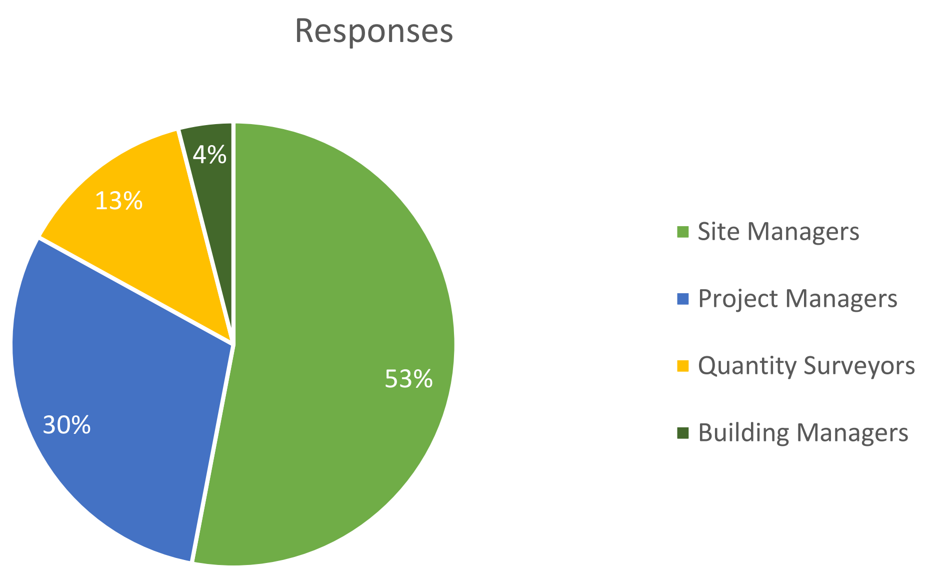


Figure 16 Main survey respondents

4.2.3.2 Labelling and grouping similar data

Feedback from the respondents was at times similar or overlapping in regards to subcontracted works, activities or materials for example, whilst one respondent would write “steel frame” another may refer to it as “structural steel work” or in relation to groundwork’s “groundwork and substructure” and “substructure and drainage” or “foundation”, and so on. As the respondents were referring to the same thing it was necessary to simplify the data in order to make it workable. Therefore, terms meaning the same thing or similar were grouped into one variable and labelled appropriately. Taking the first example above, “structural steel work” was labelled “steel”. Regarding the second example above, three variables were labelled, “groundwork”, “drainage” and “foundation”. Using these variables meant that terms given by respondents such as “groundwork and substructure” could be assigned to “groundwork” and “foundation” respectively. Once assigned to the correct variable, both the average of extent of delays and average of frequencies (maximum, most likely and minimum) reported, were used in the simulation.

4.2.3.3 Invalid data removal

In the questionnaire respondents were asked to indicate where materials or activities may be affected by delays in the supply chain. They were also asked to indicate, in percentage terms, the probability of this event occurring and its extent should it occur. One respondent when asked to indicate typical works to be subcontracted out, the probability that these works would commence after the scheduled date and to what extent they would be late (minimum, most likely and maximum) responded as follows: They named a typical area of work which would be subcontracted to specialist subcontractors but, put 0% when indicating that these works would commence after the scheduled date. This in turn indicates that starting late will not occur. The respondent also put 20, 31 and 50 indicating the maximum, most likely and minimum extent of delays. This response was invalid and subsequently removed from the data set as it was not logical and therefore not usable.

4.2.3.4 Using mean to represent outliers and data sets

For each variable mean was used as the representative of the data set as the mean, where data is normally distributed, can represent the data properly. However, a problem when using the mean is that it is very sensitive to extreme values as extreme values pulls the mean in one direction or another. This presents limitations as it lowers both the usefulness of mean as a measurement of central tendency and data set representative (Salkind, 2013). In order to provide a data set representative that is robust, extreme values must be removed. Data outliers are known as extreme values. According to De Muth (2014) an outlier is defined as:

> an extreme data point that is significantly different from the remaining values in a set of observations.

The data set is derived from 29 ($n<30$) respondents which is categorised as a small sample. To remove outliers from small data sets can prove to be a disadvantage as the data set will inevitably become even smaller. Also, not all of the variables had 29 observations. The top variables in some categories only had 5 or fewer observations. Subsequently, it was decided upon to discard only definite outliers from variables with more than 10 observations ($n\geq10$).

Those with fewer observations than 10 were not discarded from the data set. In order to detect these outliers, the box plot method was used. The stages and calculation examples for detection using the box plot method can be found in appendix (A4).

In addition to the above it was also important to avoid underrepresentation. For instance, one respondent only mentioned cladding in relation to types of material with wrong specification being delivered therefore cladding was excluded from the simulation. In order to avoid underrepresentation, only variables with 5 observations or above ($n \geq 5$) were included in the simulation regarding the material, labour and management information flows. On the other hand, 2 observations were used in developing equipment and information flow simulation scenarios. Appendix A6 presents the selection of variables in each flow. Described in the next chapter is the supply chain delays which were subsequently incorporated into developing the simulation scenarios.

4.3 Supply chain management related delays selection

During the process of identifying potential delays of any project, a huge amount of potential delays can be identified. For the purposes of this research, the related delays that may affect the supply chain and can be operationalised and have an effect on the site activity during the project, are analysed in chapter 6. The other delays that did not meet the above conditions were removed. Full details regarding supply chain related delays can be found in Appendix A2.

Chapter 5

Simulation scenarios development process

This chapter discusses in detail the simulation process, simulation model and the software used for the simulation. Moreover, this chapter discusses the verification and validation of the simulation as follows:

5.1 Introduction to Microsoft project 2007: the introduction sheds light on the software used in the simulation process.

5.2 Introduction to CPM and PERT analysis: an introduction to CPM and PERT techniques.

5.3 Linking delays to activities in the critical path network: this section illustrates the process of linking the data gathered in the main survey to the critical path network.

5.4 The simulation scenarios: this section discusses the process of developing the simulation scenarios, the network and the process of linking delays to activities on the critical path network project and the analysis technique.

5.5 The simulation process: this section provides a detailed description of the simulation scenarios development process.

5.6 The validation and verification models: this section discusses the validation and verification techniques in general and how the research adopts them.

5.7 Summary

5.1 Introduction to Microsoft project 2007

5.1.1 Introduction

Project management has developed in many ways due to the advancement in technology and software designed specifically for the task. In particular, Microsoft developed the MS Project 2007 application in order to provide for this niche in the market. The following details an examination of the effectiveness of the application.

5.1.2 History of MS Project 2007

According to Stallsworth (2009), MS project was introduced to Microsoft for DOS in 1984 by a company that worked for Microsoft. Microsoft purchased the complete software rights and then developed version 2, making it available world-wide immediately. In 1992, when Windows was more widely used, Microsoft designed a GUI version of MS Project and gradually developed the programme creating new versions over the course of a few years until finally they came to MS Project 2007. Four versions are available in the market:

1 Microsoft Office Project Standard 2007
2 Microsoft Office Project Professional 2007
3 Microsoft Office Project Web Access 2007
4 Microsoft Office Project Server 2007

The MS Project software is not in itself complex when used for basic/simple project management but, the numerous options available can prove to be overwhelming and unnecessary for simple projects, subsequently certain features within the programme remain unused, except by specific businesses. One advanced project management tool incorporated in the software is the option to create PERT (Program Evaluation Review Technique) charts. PERT is a methodology initially created in 1950's by the US Navy, Special Projects Office for the Fleet Ballistic Missile Program, which enabled a method to present a project in the form of a network diagram. According to Stallsworth (2009) Mr Willard Fazar, whom lead the team, commented on the system and stated features within the system were:

> A precise knowledge of the sequencing of activities' and 'a careful time estimate for each activity, ideally with a probability estimate of the times the activity might require.

Although some project managers find this tool useful, it is however highly advanced and may prove too advanced for many organisations. (Stallsworth, 2009)

5.1.3 MS project 2007 Summary

Incorporated in the Standard version of MS Project 2007 are robust and useful tools for resources, costs, reporting, task management, the availability to create Gantt charts and to trace activities and their duration. Depending on the infrastructure of project management the tools are user friendly and not complicated. Based on the previous discussion regarding MS project 2007, this software will be used in developing the simulation scenarios as it is clear, user friendly, not complicated to use and accessible.

5.2 Introduction to CPM and PERT analysis:

5.2.1 Introduction

According to Weaver (2006), the critical path method (CPM) scheduling system is a scheduling system created in the 1950's by Du Pont, and still in development at the time of the program evaluation review technique (PERT). The main differences between the two systems were the introduction by PERT of uncertainty in scheduled durations and moreover, the invention of the 'critical path'. Both CPM and PERT used the ADM (Arrow Diagramming Method) technique – where activities are represented by arrows. One key differentiating factor was that the duration of Du Pont's business activities, to a certain degree of accuracy, could be estimated. This estimation was based on known production rates and quantities therefore, CPM concentrated on the optimisation of costs by balancing the resources. PERT however, concentrated on establishing the probability of an event occurring at a future date. Ultimately, PERT and CPM merged in the 1960's to form a generic ADM, 'network based management system'.

Commonly used today is the Precedence Diagramming Method (PDM), published in 1962 as a non-computer method to scheduling. Although PERT can be applied to PDM it can only do so where the PDM network applies 'Finish-to-Start' links with zero duration.

5.2.2 Application of PERT

PERT was devised as an ADM scheduling technique meaning that the assumptions made were such that each individual activity ends at a 'node', from which other activities commence. Therefore, no room exists for overlapping activities. Schwalbe (2015) stated that the steps to apply PERT are as follows:

1. Develop a logic network by establishing 3 time estimates per activity.
2. Using the PERT critical path (based on t_e), the 'critical path' is determined
3. Analysis of 'the longest path' can then be carried out through the PERT calculations in order to establish the 'probable' completion date of a schedule.

5.2.3 PERT Calculation

According to Gopalakrishnan (2015), the aim of PERT calculations is to give an estimation of the time elapsed between the start of an activity to the end of an activity and determine the probability of completing the activity by a given end date. In order to accomplish that, it is necessary to estimate three possible durations per activity based on the following:

- Optimistic – the least required time in order to carry out the work
  - known as t_o or a
- Most Likely – the expected required time in order to carry out the work
  - known as t_m or b
- Pessimistic – the maximum required time in order to carry out the work
  - known as t_p or c

Both optimistic and pessimistic estimated durations are established under normal working conditions, dismissing defined risks. These durations are estimated to have a 1:100 or 1% possibility of being exceeded (pessimistic) or bettered (optimistic). The 1% rule is utilised in order to maintain a reasonable data range.

The formula used to calculate in PERT according to Taylor (2007) is as follows:

Mean = optimistic + (4 x most likely) + pessimistic / 6

Traditionally expressed as**: Mean** = a + 4b + c / 6

Where mean (t_e) is the expected duration per activity having a 50% possibility of achievement or bettered, and a 50% possibility of being exceeded.

Based on a similar concept to the CPM, the critical path in PERT is calculated using the sequential path in the network which is the longest. The longest path is then calculated using the 'mean', or 'expected' duration as oppose to the t_m durations. Nevertheless, as stated, although PERT is similar to the CPM, PERT will ultimately deliver longer schedule duration as the sequence followed may be different to that followed by the CPM. (Schwalbe, 2015).

Most activities tend to have a more pessimistic shift due to the fact that the amount of events that could potentially cause a longer than expected duration are considerably greater than those that could shorten the expected duration.

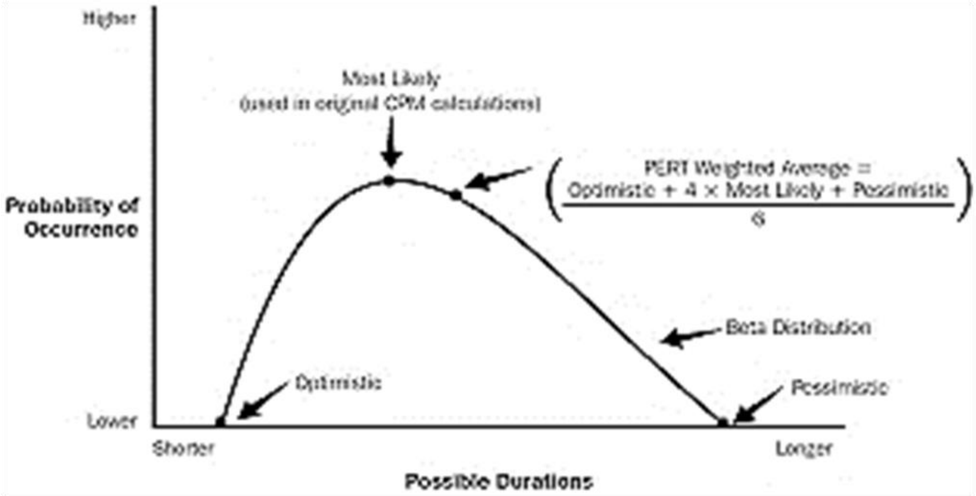


Figure 17 PERT estimations adapted from (Shivers and Halper, 2012)

The initial formula used in PERT is simplistic and intended to facilitate calculation times which are reasonable. In 1959, the developers stated in a paper which they presented to Institute for Operations Research (INFORMS):

> This simplification gives biased estimates such that the estimated expected time of events are always too small. It was felt that, considering the nature of the input data, the utility of the other outputs possible from the data and the need for speedy, economical implementation the method (is) completely satisfactory.

Only the path that resulted in the greatest value, the ‘controlling path’, was given consideration when variance analysis was carried out at a certain node.

Once the expected duration has been determined it is necessary to establish a completion date which betters a 50% probability of being completed. This enables the calculation of measurement in variability of data by calculating the Standard Deviation (within the data set). As the variability within the data increases this will have the same effect on ‘one standard deviation. Ultimately, ‘one standard deviation’ will consistently have the equivalent percentage of occurrences i.e. probability of completion will remain the same.

As stated previously, the SD calculation gives a range indication in order to assess the probability of completion on a certain date. PERT uses the following simplistic approximation formula:

Standard Deviation = pessimistic – optimistic / 6 or SD = (c – a)/6, for each individual activity on the ‘Critical Path’. (Taylor, 2007)

Moreover, PERT used the above calculation as computing power at the time of development was limited therefore, the calculation enabled computations to process within a reasonable period.

According to Kendrick (2007), 1:4:1 PERT estimates weight are considered as default weight estimates and are widely used as it is more simple and clearer.

The misuse of the term ‘PERT chart’, meaning that PERT was a Network Diagram, began whilst scheduling was in its early days when PERT and CPM, (both using Activity-on Arrow techniques) merged and became an ADM scheduling system. Although PERT ‘requires’ a logic diagram in order to apply both the process and calculations it is not ‘the same as’ drawing logic/network diagrams, as is the case in CPM, RDM, Critical Chain and methodologies. This misuse of the term was compounded when MS Project used the term ‘PERT chart’ when describing its ‘Precedence Diagram Network’ (PDM), when in fact prior to the publication of the PDM paper PERT had already been developed.

5.2.4 PERT limitations

1. The only variable is time – PERT is only concerned with time even when analysing other factors, such as technical performance changes and resources. PERT analyses these factors only where they are affecting time excluding quality/quality control and price. As this research main aim is to analyse the impacts of supply chain management on construction projects in terms of time delay, this limitation can be considered as an opportunity to help in achieving the objectives of this research.

2. One distribution – the accuracy of calculations is affected by this limitation. The range of outcomes per activity can be varied according to the work involved within each activity. Other, more modern systems, have a wide range of distributions which ultimately produce a more accurate reflection on the variability of each activity and include tools such as: Beta, Normal (Gaussian), Triangular and many more.

3. SD calculation is approximate – a significant error within PERT is the Standard Deviation calculation. Complex calculations can be carried out with ease on modern computer systems and are necessary to accurately measure the Standard Deviation of a data set.

4. Calculation of the Single Pass – generating a single value, the PERT single pass calculation produces limited results when compared to other techniques which produce hundreds of simulations generating accurate and valuable information.

5. PERT Merge Bias – PERT calculations neglect recognition of the possibility that other ‘sub-critical paths’ could, under certain circumstances take a longer time to complete and only takes the ‘critical path’ into consideration.

5.2.5 Summary

According to Kerzner (2009), PERT is a well-respected technique having made an important contribution in regards to the development of project controls and more accurate risk estimations. One of its main advantages is its extensive planning, enabling the decision maker to concentrate on particular areas to keep projects on schedule by using the critical path analysis which highlights problems that, when using other methods, are not obvious. Moreover, Gopalakrishnan (2015) stated that PERT, critical path method (CPM) and critical path analysis (CPA) are the most important network analysis techniques. In addition, PERT also facilitates the ability to determine the likelihood/probability to meet deadlines by developing alternative plans where necessary. The Standard Deviation (SD) together with the probability of accomplishment can also be examined. The ability to evaluate the ‘effect of changes’ can be found in the programme allowing for various scenarios to be input in order to determine the overall effect/outcome on the project. Evaluation of deviation of the actual required time per activity against the predicted time can also carried out. Finally, PERT facilitates decision making between the contractor and customer by allowing a wide range of sophisticated data to be presented to both parties in a well organised and logical format. Based on the arguments before, PERT, CPM and CPA techniques are suitable for this research and help to achieve the research objectives.

5.3 Linking delays to activities in the critical path network

5.3.1 Introduction

To develop the simulation scenarios, all delays that are related to the supply chain gathered in the main survey were synchronised to the critical path method network. In order to do so, supply chain delays from the survey were matched with the relevant activity/activities. As an example: the main survey presented steel as a type of material that can be delayed due to shortage in quantity or damaged when transported from the warehouse therefore, all activities that required steel will be delayed such as: concrete work, steel work, columns and reinforcement work, ground beams, columns work ground floor, slab work, concrete work, steel work, steel and reinforcements work, ground beams, columns work ground floor and slab work.

Moreover, MS project 2007 software, allows the process of adding notes to activities which facilitated the process of linking activities with supply chain elements in order to arrange the delays. Figure 18 below, represents an example screen shot of linking the delays with the activities on that research.

133		Management	15.5.3 Client Acceptance	0.5 days
134		Management	15.5.4 Quality	0.5 days
135			**16 Slab Work**	**16 days**
136		Labour	16.1 Jornery work	2 days
137		Material	16.2 Brick supply	1 day
138		Labour	16.3 Brick laying	1 day

Figure 18. Linking delays with activities

5.3.2 Applying delays in the CPM

In order to analyse the extent to which supply chain management may impact project performance, the highest pessimistic value of the delays gathered from the main survey was synchronised into the activities on the critical path network.

On each scenario development, the highest pessimistic value of delays related to the tested scenario flow were synchronised from the main survey to the pessimistic activity duration of the related activity, for example:

On the labour flow scenario, all activities that are not related to that flow have the optimistic duration equals the most likely duration. On the other hand, related activities to the labour flow pessimistic duration will be the pessimistic duration plus the highest pessimistic value of the related delay from the main survey results.

Moreover, all details of applying the delays to the simulation scenarios can be found in appendices (B1 and B2)

5.4 The simulation process

The main aim of the simulation process is to analyse the impacts of supply chain management on construction projects performance. In order to achieve that, a simulation process that combines project activities and supply chain delays needs to be developed with the use of Microsoft Project 2007 software. The simulation scenarios use a critical path method network that was obtained from one of the residential housing projects visited as discussed in the previous chapter and the results of the main survey were synchronised with the activities of the selected critical path method network. More details about the simulation process is discussed in detail in the following sections.

5.4.1 Simulation model assumptions

The following assumptions were made in developing the simulation scenarios in order to achieve the aim of the simulation process, make the simulation process clear and reduce complexity as follows:

1- The critical path method network used in developing the simulation scenarios, which represents the skeleton level of a residential housing project, was obtained from one of the projects visited in the preliminary investigations.

2- Activities durations in the critical path method are fixed. Fixing the duration of the activities helps in making the impact from delays in the supply chain activities clearer and reduce both complexity and variation.

3- The delays data in the simulation scenarios are the data that was synchronised from the questionnaire and incorporated with PERT (Program Evaluation and Review Technique) risk analysis.

4- The simulation scenarios present the impact from information, material, labour, equipment and management information delays each separately and together.

5- For research purposes, the main focus is on the pessimistic scenario of information, material, labour, equipment and management delays as it helps to analyse to what extent the construction supply chain may impact project performance.

6- Activities are not able to avoid prior activity delays. Sometimes, during projects when a delay occurs as a result of one activity, other activities can start as they are not depending on the delayed activity. This may result in slightly overstated results but, in order to clarify the impacts of supply chain on project performance resequencing activities is not allowed.

7- Information delay is the client's responsibility and all other delays are the main contractor's responsibility.

8- As this research examines time delays as a risk on construction projects performance, the pessimistic scenarios of the delays are analysed compared to the actual (most likely) scenario based on PERT analysis calculations.

5.4.2 The critical path network

As mentioned before, the critical path network used in developing the simulation scenarios was obtained from one of the sites visited. The critical path network (CPM) represented the skeleton level of a medium residential housing project which is considered as a typical residential housing project in Jordan. The critical path network of that project consists of 18 activities, 140 sub-activities and 50 resources. Resource examples can be found in table 25.

Resource Name	Resource Type	Resource Name	Resource Type
Hammer	Cost	Surveyor	Work
Bulldozer	Cost	Client Representative	Work
Dumper	Cost	Sand	Material
Scaffolding	Cost	Steel Tools	Material
Vibrator	Cost	Concrete	Material
Roller	Cost	Water	Material
Joiner	Work	Plugs	Material
Project Manager	Work	Cement	Material
Site Engineer	Work	Steel Reinforcements	Material
Scaffolder	Work	Pipes	Material
Blacksmith	Work	Bricks	Material
Bricklayers	Work	Windows & Doors	Material
Electrician	Work	Timber	Material
Plumbers	Work	Steel	Material
Plasterer	Work	Tools	Material
Labour	Work	Drainage	Material

Table 25 Resource examples

Table 25 presented some of the resources that were used in the project and as the graph shows, there are 3 types of resources to select between in MS project 2007 as follows:

1- Material
2- Work
3- Cost

The following, figure 19, presents part of the work breakdown structure of the project, showing 2 main activities and the sub activities related. The full work breakdown structure of the project can be found in Appendix (B3).

WBS	Task Name	Type
14	**Slab on grade**	
14.1	**Joinery work**	*Labour*
14.2	**Casting Concrete**	*Labour*
14.3	**Casting Concrete**	*Labour*
14.4	**Slab on grade phase review meeting**	
14.4.1	Phase Objectives review	*Management*
14.4.2	Match Achievement Objectives	*Management*
14.4.3	Client Acceptance	*Management*
14.4.4	Quality	*Management*
15	**Columns work ground floor**	
15.1	**Steel Work**	*Labour*
15.2	**Joinery work**	*Labour*
15.3	**Concrete supply**	*Material*
15.4	**Casting concrete**	*Labour*
15.5	**Columns work ground floor phase review meeting**	

Figure 19 Work breakdown structure

Figure 20 following presents the selected critical path network which was obtained from one of the projects including a section enlarged as an example. The relations between activities were added to the network, there are four types of relations in MS project:

1- Start to Start
2- Start to Finish
3- Finish to Start
4- Finish to Finish

The critical path network consisted of 18 main phases and 158 activities. The project plan indicated that the project started on the1st January and finished on the 1st July of the same year. The project's duration in total was 183 days.

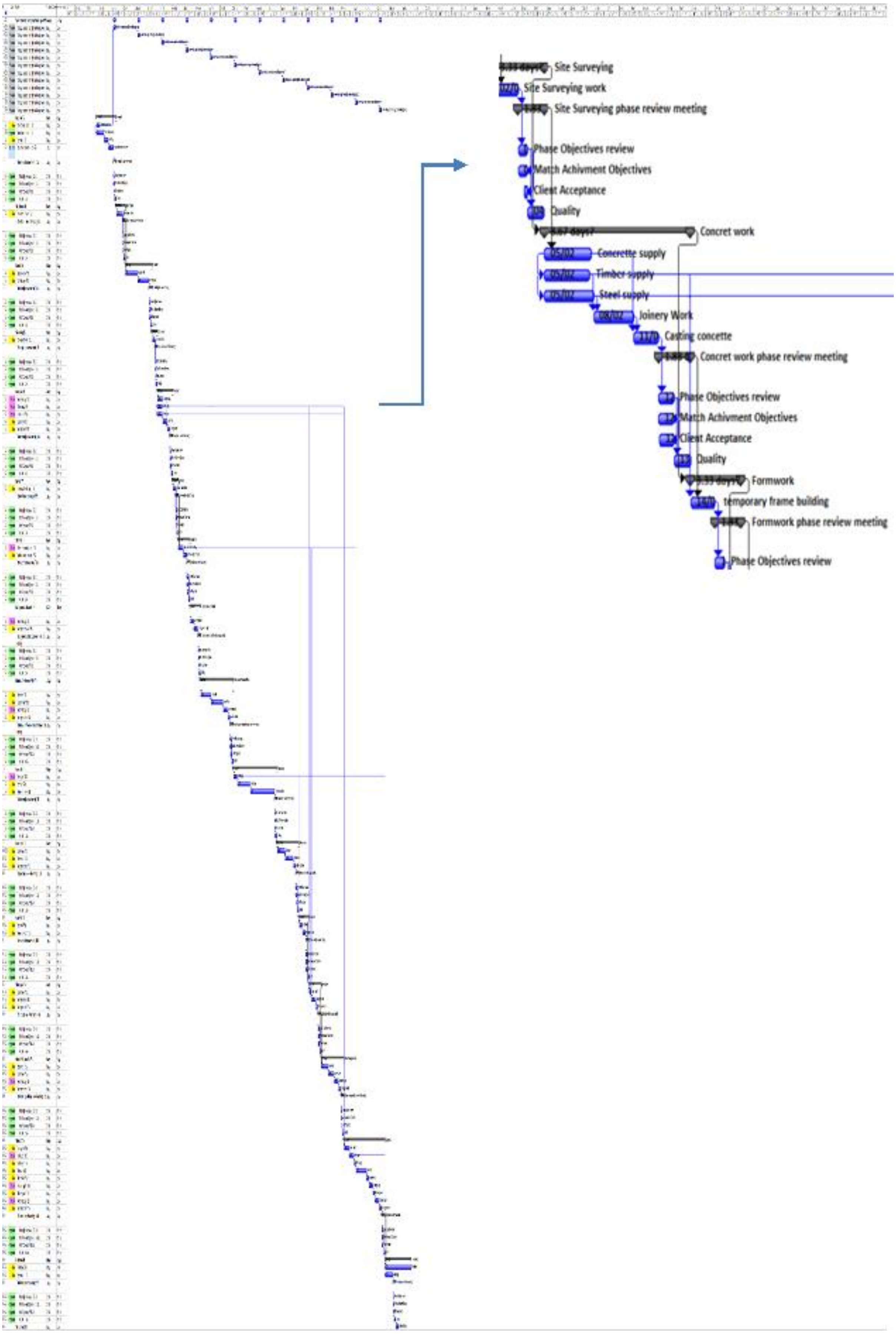


Figure 20 Initial critical path network

5.5 The simulation scenarios development process

The network contained all of the project activities with the optimistic, most likely and pessimistic duration values of each activity. The most likely duration value represents the actual real time for the activity to finish, as that duration value represents historical data.

In order to reduce the complexity and to make the process clearer, the delays were categorised into 5 categories which are: material, labour, equipment, management and information delays to match the construction supply chain flows identified in this research. The simulation scenarios cover each category of the delays and its impact on the critical path network both separately and combined. As this research examines time delays as a risk on construction projects performance, the pessimistic scenarios of the delays will be analysed and compared to the actual (most likely) scenario in order to reduce complexity of other scenarios and to test to what extent supply chain delays may impact on projects performance in terms of time.

The following illustrates the steps taken in developing the simulation scenarios:

1- The critical path network of the project was obtained using MS project 2007 with the resources and activities durations.
2- Activities on the critical path network were linked to its appropriate construction supply chain flows which are: material, labour, equipment, information and management.
3- PERT technique was applied to the critical path method in order to calculate the estimated optimistic, most likely and pessimistic activities duration.
4- In order to test the impact of each construction supply chain flow component separately, the optimistic duration was set to equal the most likely duration for all activities on the critical path network.
5- On each scenario development, the highest pessimistic value of delays related to the tested scenario flow were synchronised from the main survey to the pessimistic activity duration of the related activity, for example: on the labour flow scenario, all activities that are not related to that flow have the optimistic duration and equals the most likely duration. On the other hand, related activities to the labour flow pessimistic duration equals the pessimistic duration plus the highest pessimistic value of the delay from the main survey results.

5.5.1 The simulation scenarios

The simulation process discussed earlier, developed 6 scenarios as can be seen in figure 21. These scenarios represent the pessimistic scenarios of supply chain related delays that occurs in a project individually and combined. The project was carried out by the main contractor who is responsible for all delays in the research apart from the information scenario which is the clients responsibility.

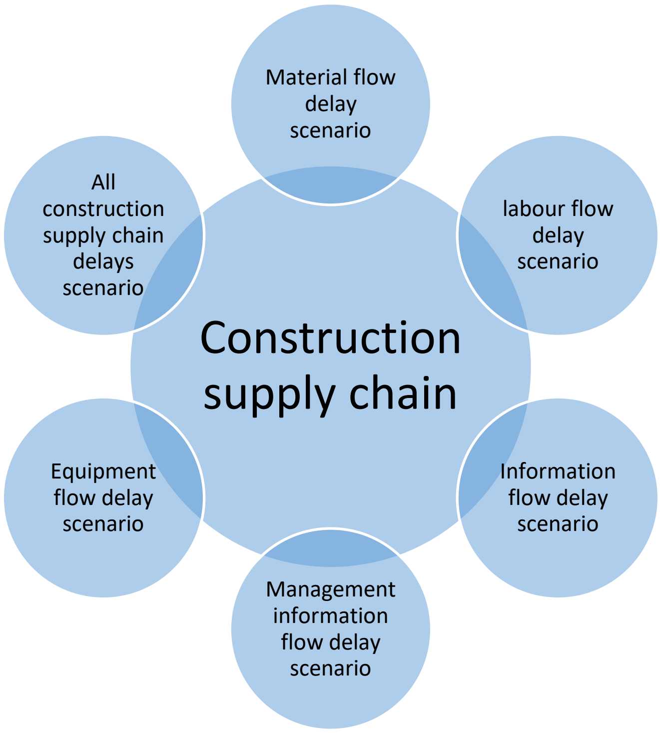


Figure 21 Simulation scenarios

Each scenario aimed to identify the impact of its related delay type on the project. As an example; the material delay scenario can help in analysing the impact of material delays on the project and to what extent that flow may have an impact on the project.

5.6 The verification and validation models:

This section discusses the verification and validation process of the simulation scenarios development.

5.6.1 Model verification

Model verification refers to the process of ensuring that the implementation of the conceptual model, logical structure and the input parameters were carried out correctly on the computer. Although, it can be a very complicated and difficult process to debug large scale simulation programs especially where huge amounts of logical paths exist.

Law and Kelton (2000) contributed the following verification techniques as table 26 presents:

Technique	Description
1	Calculate the sample variance and mean for each input based on the inputs probability distribution and compare the result for each input with historical data to each input to get a view if the results are generated correctly
2	More than one person is needed to review the computer program in large simulation models
3	Check the simulation programs after each event and compare the results with manual calculations.
4	The animation of the simulation outcome can be observed.
5	The simulation model needs to run under different parameters settings with reasonable outcomes.
6	The simulation program should be run with simple assumptions were the results are already known or can be calculated.
7	Debug and write the computer program in subprograms or modules while developing the simulation model.
8	To reduce the amount of programming needed, use a commercial simulation package. However, care must be taken when the commercial package is recently released as it may have errors.

Table 26 Simulation verification techniques

The first 7 techniques are more concerned with the review of the simulation program coding which is more applicable to higher programming levels or general purpose programs such as: C and FORTRAN. On the other hand, the last technique is more applicable in the process of developing simulation scenarios using a commercial simulation program.

Moreover, Sargent (2003) contributed that using a commercial simulation package generally increases the possibility of the program to be correct and reduce the errors. The main concern of the verification is to ensure that the used simulation program is error free and implemented on the computer correctly.

In this research, MS project 2007 (V12.0) particular-purpose software package was used. As this software is a ‘ready to use’ package, users does not have to be concerned with programming and coding which saves time and reduce the risk of errors. Moreover, MS project 2007 is a closed source code which indicates that the coding of the software cannot be checked (Marmel, 2011).

All of the arguments presented above suggest that the verification process of the program is fulfilled by using a well-known software package.

5.6.2 Validation

The main concern of the validation process is the accuracy of the model in representing a real system. In other words, validation is all about building the correct model. Law (2014) stated that, gathering high quality data and information increase the model's validity. There are many ways of gathering high quality data such as: system observations, the use of existing theories, subject matters expert's views and results from similar modules.

On the other hand, developing simulation scenarios needs high quality data which means developing such a thing in isolation is a very complicated process with high risk threats. Simulation scenarios development process needs interactions with subject matter expert's views, observations and real systems.

The data gathering process presented in this research, is pursuant to the arguments mentioned in this section as the data and information used in the process of developing the simulation scenarios was acquired from the main survey and the preliminary investigation. The regular site visits allowed the observation process of a real system with an insight of the subject matters expert involvement and comments during the project. The regular visits also allowed the researcher to identify supply chain practices in construction projects and its associated delays which were used in the simulation scenarios development process. Moreover, the critical path method (CPM) network which is the main component of the simulation process was acquired from one of the visited projects. The critical path method network was prepared by an expert planning engineer that has been in the profession for over 6 years. With such professional history and expertise, it can be argued that the acquired critical path method network which included common activities, realistic durations and the logic of medium residential housing projects in Jordan, is reliable and can be a good representation of a real system common practise in the construction industry. In addition, the survey, which was performed through circulating questionnaires to experts in the construction industry, allowed gathering data related to supply chain delays in terms of the delay types and durations which helped in developing the simulation scenarios. To conclude, based on the discussion presented, the data gathering process for the simulation scenarios development process in this research can be considered as high quality data which increases the system validity as Law (2014) proposed.

However, Sargent (2003) suggested some other validation techniques such as: face validity, animation, degenerate tests, extreme condition tests, trace, multistage, event, internal, event, predictive validation, etc. This research used the extreme condition test, event validation, animation and trace validation techniques which are discussed below together with high quality data as explained previously.

5.6.2.1 Extreme condition test

According to Sargent (2013), extreme conditions test refers to the process of checking if the model output and structure is reasonable for any unlikely combination and extreme levels or factors in the system. For example: if the ‘in process’ inventory is zero then the ‘output’ in the production line is zero. In this research, simulation scenarios were tested individually by checking the duration of the scenarios before applying the delays and checking if it equals the duration of the original critical path network and all were equal. In other words, the deterministic duration of each scenario, before applying the delays, was equal to the original duration of the project.

5.6.2.2 Animation

Sargent (2013) stated that animation is a validation technique that refers to the display of the models operational behaviour graphically as the system moves in time. For example, parts movement in a production line can be displayed during the simulation. In this research, MS project 2007 software was used in developing the simulation scenarios and the operational behaviour of the model can be displayed graphically. Moreover, links that connect activities to each other and to the delays can be seen and traced.

5.6.2.3 Event validation

Sargent (2003) stated that even validation refers to checking the similarity between the simulation modules events of occurrence to those in a real system. For this research, this can be seen in the network as delays were positioned to precede activities and a summary activity sheet was used to determine the duration of the delayed activity. Several tests were performed in all simulation scenarios and all results proved to represent the real system.

5.6.2.4 Trace validation

According to Sagent (2003) trace validation refers to the process of tracing the behaviour of specific entities in the model and to determine the accuracy and correctness of the logic of the model. Moreover, Meyer, Nawrocki and Walter (2008) stated that, trace validation ensures that the information is up to date and correct.

The results of the simulation scenarios were also validated using the trace validation technique in order to ensure it is correct and up to date. All values of the delays were compared to the questionnaire results before it was added to the CPM network and then after it was incorporated to the network to make sure that the duration of each task is correct and equals the tasks duration in addition to the delay. Appendices D and E illustrate the detailed trace validation process for all simulation scenarios to ensure that the results are correct and logical.

5.7 Summary

This chapter presented the simulation scenarios development process, highlighting MS Project 2007 as the software used in the simulation process, PERT and CPM as the analysis techniques and the process of linking delays to the critical path network. Moreover, each element of the simulation process was discussed in detail providing justifications for its use in fulfilling the research needs. In addition, this chapter highlighted the validation and verification techniques that were adapted in this research

Chapter 6

Discussion of the results

Presented and discussed in this chapter are the results of the simulation scenarios:

6.1 Results of PERT analysis to the initial critical path network: this section describes the nature of the CPM network after applying PERT analysis.

6.2 Results of the simulation scenarios: this section presents the CPM network of all construction supply chain flows obtained from the simulation scenarios.

6.3 Implications of the results: this section presents an analysis of the simulation scenarios results and highlights the importance of providing time buffers for activities in construction projects.

6.4 SCM integration: this section discusses the integration of supply chain management.

6.1 Results of PERT analysis to the initial critical path network:

As was discussed in the previous chapter, the critical path network was obtained from one of the sites visited in the data collection phase. Figure 22 displays all phases in the project.

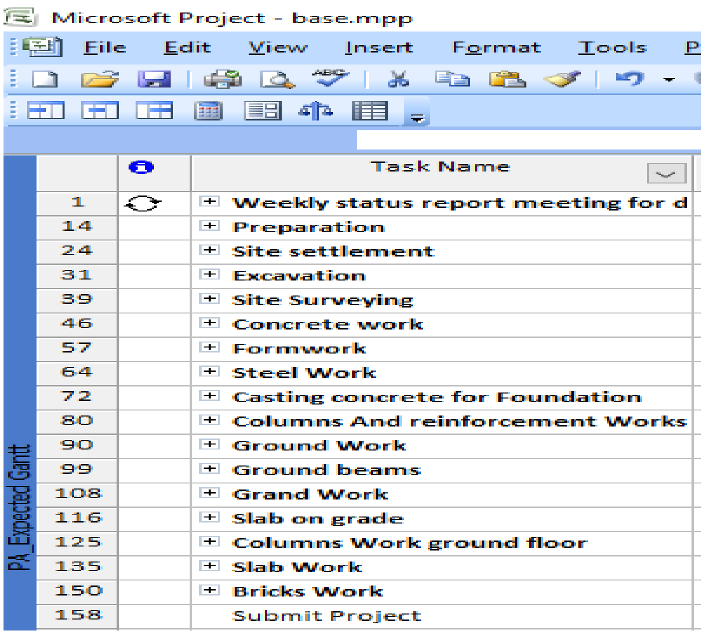


Figure 22. List of all phases in the project

As can be seen in figure 22, the critical path network consists of 18 main phases and 158 activities. The following graph, figure 23, presents the initial critical path network after applying PERT analysis which is referred to as the actual critical path network.

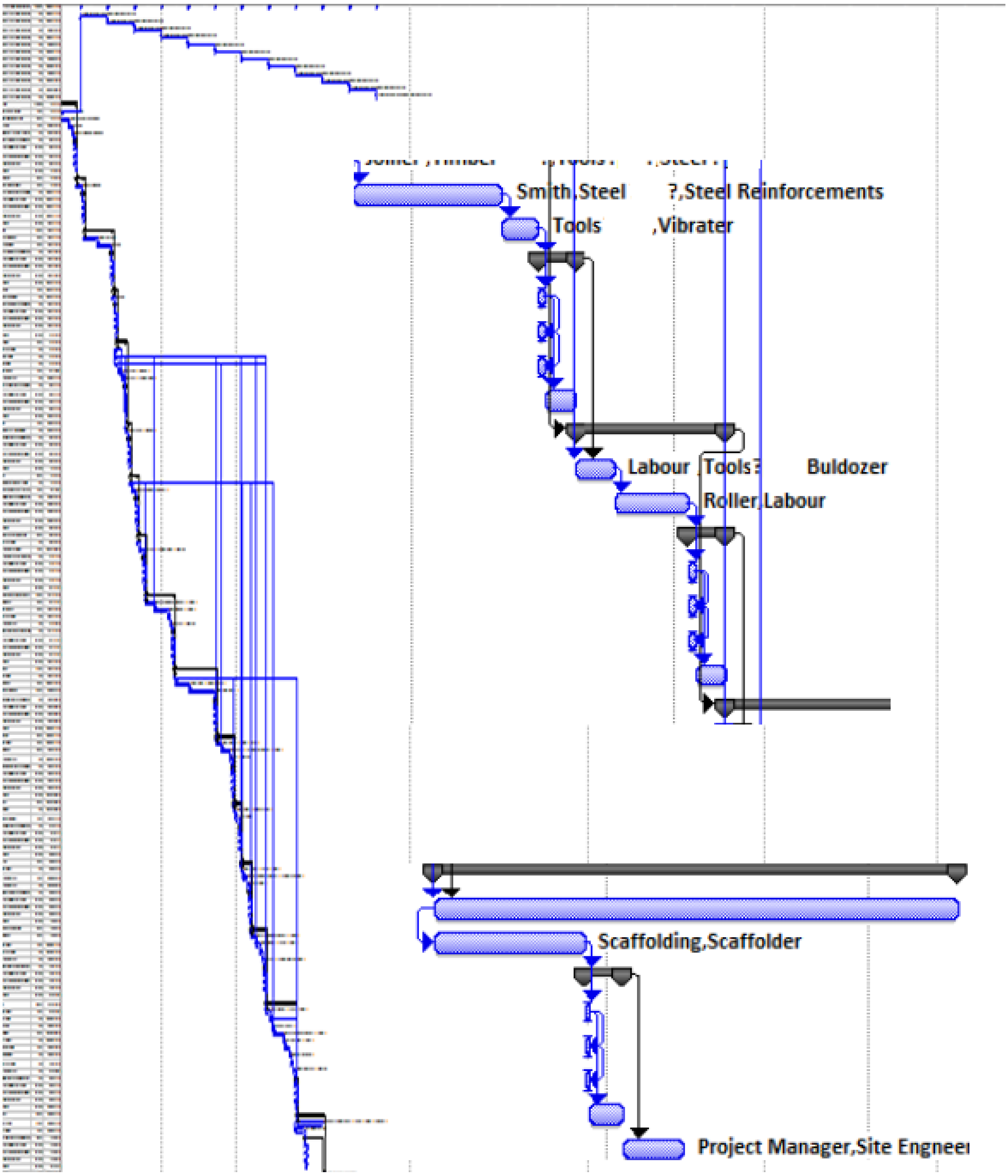


Figure 23 Actual critical path network

Applying PERT analysis to the initial critical path network had an impact on the duration of the activities as was expected and discussed earlier in the PERT analysis discussion section. The project started on 1st of January and finished on 17th of May of the same year, which equates to a duration of 138 days. The initial project after applying PERT analysis is referred to as the actual project for simplification purposes. The variance between the initial and actual project is 45 days. This variance can be justified as PERT analysis gives more weight, specifically 4 times more likely, than the most likely scenario to the optimistic and pessimistic scenarios in order to recalculate the duration of activities.

6.2 Results of the simulation scenarios

The results of the simulation scenarios were expected to be different than the original critical path network as the scenarios represent supply chain delays that have an impact on the project in terms of time delays. As the pessimistic scenarios are the focus of this research, the logic of the software placed delays in series, which indicates that the total delay of any scenario is the sum of all separate delays related to the flow simulated in the network.

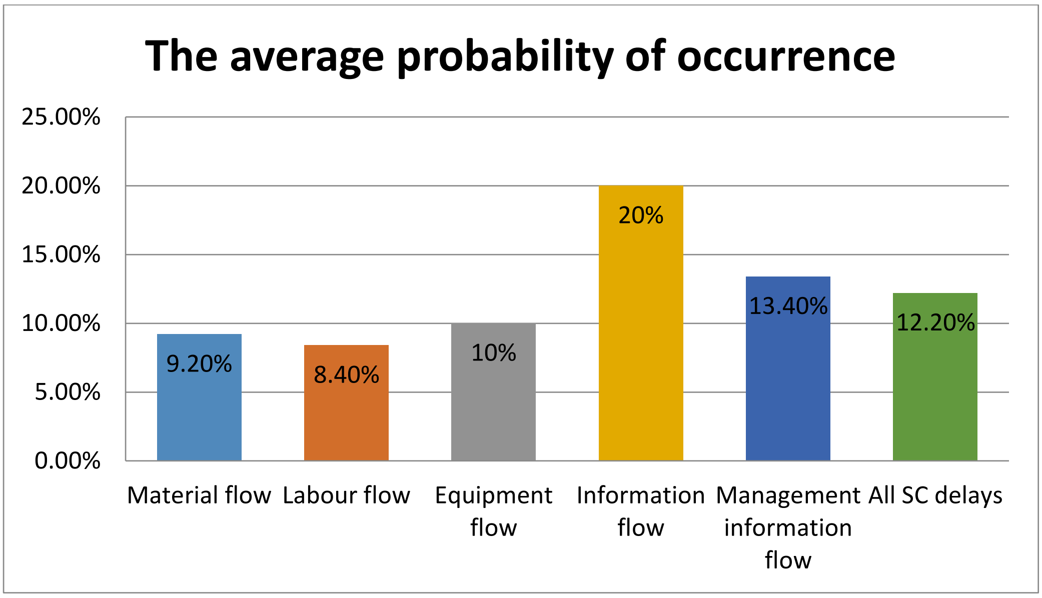


Figure 24 Average probability of supply chain delay occurrence

The following section presents the results of the simulation scenarios. As was discussed in the previous chapter, the simulation scenarios are presented in the following table 27.

	Simulation scenario
1	Material delay
2	Labour delay
3	Equipment
4	Management
5	Information
6	Material, labour, equipment, management and information delays all together

Table 27 Simulation scenarios

6.2.1 Material flow scenario:

As discussed earlier in the investigations section and the main survey, the material flow delays were categorised into three types as follows:

1- Material delivered later than scheduled delivery dates
2- Material delivered with wrong specification
3- Material damaged on site.

The following figure 25, presents some examples of the material flow delays pessimistic scenario in the CPM network.

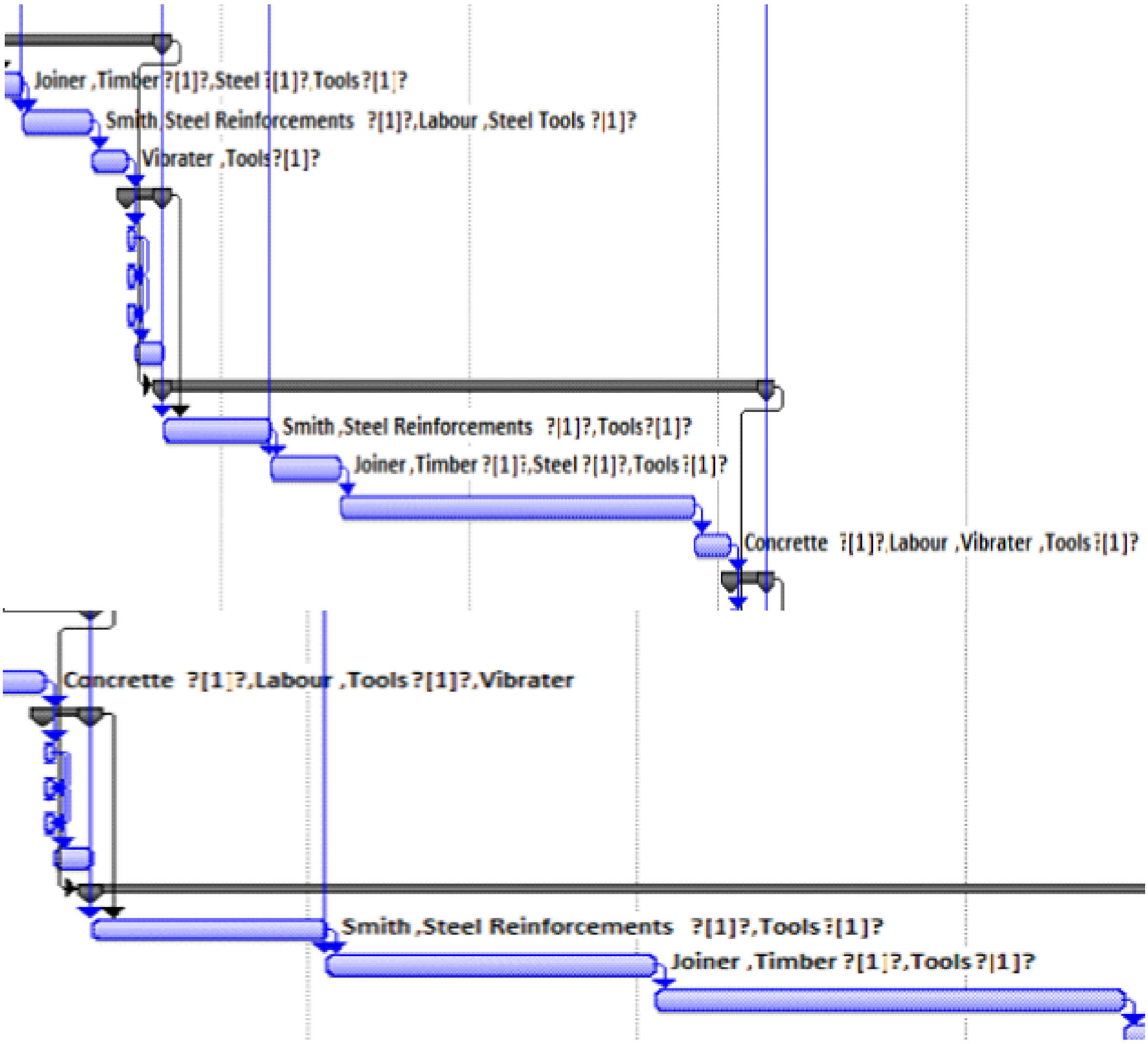


Figure 25 Material flow delays scenarios example

Material delay:

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5	138	0	0
Material delay	1/1	25/7	207	69	50%

Table 28 Material flow simulation results

As can be seen in the simulation results in table 28, the project was delayed by 50% of its duration. That huge impact reveals the importance of managing the material flow as it can lead to overrun costs and delays. Moreover, the results of the main survey suggested, the average probability of the material flow delay's occurrence is 9.2%

The main survey results suggest that material flow delays can be the result of three main sources: late delivery, wrong specifications or quantity and damaged materials on site as can be seen in figure 26 below. The results suggest that the highest problem in materials flow is materials delivered with wrong quantity or specifications which can be due to a problem in the supplier's company and/or the contractor's company. Using shared applications and IT software can help to ensure the right quality and quantity has been ordered and processed from both parties.

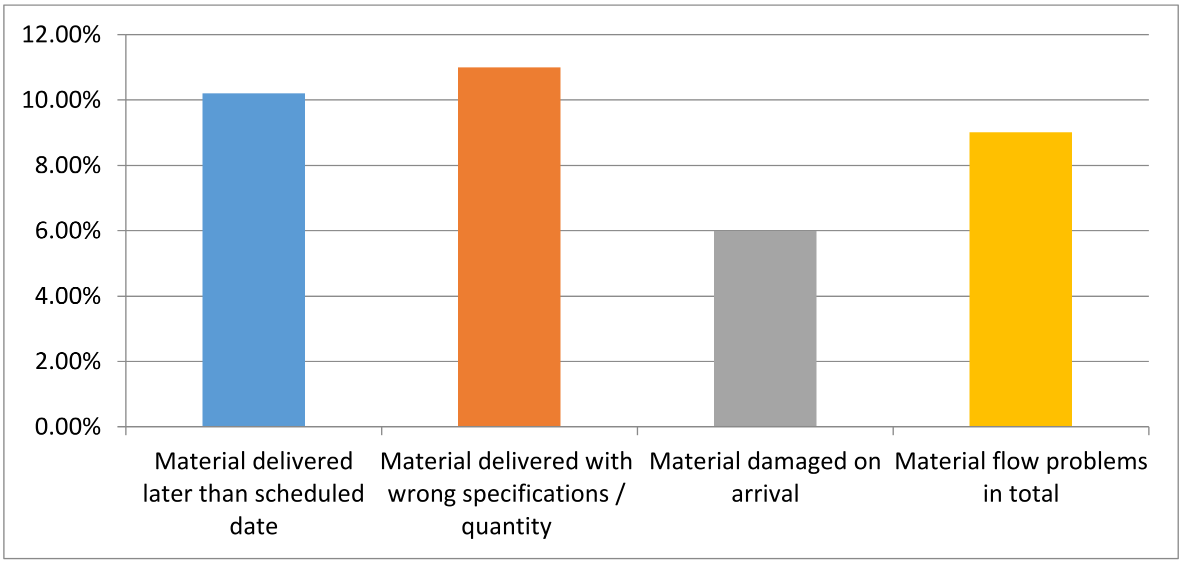


Figure 26 Material flow delays

Moreover, the results from the simulation scenario and the main survey suggest that material flow plays a major role in project delays which have an impact on project activities causing delays and additional costs. According to Donyavi and Flanagan (2009), there are five categories in the process of managing materials and failure to address them may result in some problems. The categories are:

1- Specification and measurement
2- The purchasing and procurement process
3- Transportation to site, order checking, off loading and on site storing
4- Financial and administrative payment process.
5- Material use on site and wastes removing.

According to Sears (2015), another concern is inaccurate material planning which may lead to the following risks: contract overrun time and not being able to meet the contracts obligation to submit the project at the agreed time to the client due to the lack of materials, over ordering materials may tie up the contractor's finances as it has cash flow implications and on the other hand, the over ordered materials may disrupt the construction site and take additional storage place that can be used for other activities. Moreover, materials cost is an important aspect to discuss as it represents a percentage of the total project cost which may cause disruptions to the material flow in the project. Accurate material planning plays a major role in projects success. All process of distribution, transportation, use and handling of material should be held and planned accurately by an experienced and competent staff member.

Other problems that may disrupt the process of material flow in the construction industry are:

1- Late material orders result in project delays
2- Random times of material deliveries results in interrupting works and causing delays.
3- Lost or damaged material because it was stolen or kept in insecure storage places.

The above discussion suggests that the construction industry in Jordan has some problems regarding materials management and failure to deal with that serious element of the construction chain may result in delays and additional costs.

The following presents possible solutions for material delay problems:

1- Initiation of long term relationships between contractors and suppliers

According to Dornfeld (2012), Supply chain partnerships has proved important in the manufacturing industry and has resulted in many gains such as: shorter product development, inventory reductions, improved delivery service, increased market share and improved quality. This can open an opportunity for the construction industry to gain from the manufacturing industry experience.

2- Supplier early involvement with the contractor in the design stage

Giving suppliers the opportunity to discuss the different aspects in the design stage of a project may help the main contractor in improving the projects plan in terms of available material, specifications and other issues from the supplier's perspective. Moreover, the early involvement of suppliers helps in increasing their awareness to the problems that can be a result of the material flow process, delivery and material planning issues. The following figure 27 represents the most pessimistic material delays which was used in developing the simulation scenario based on the main survey results.

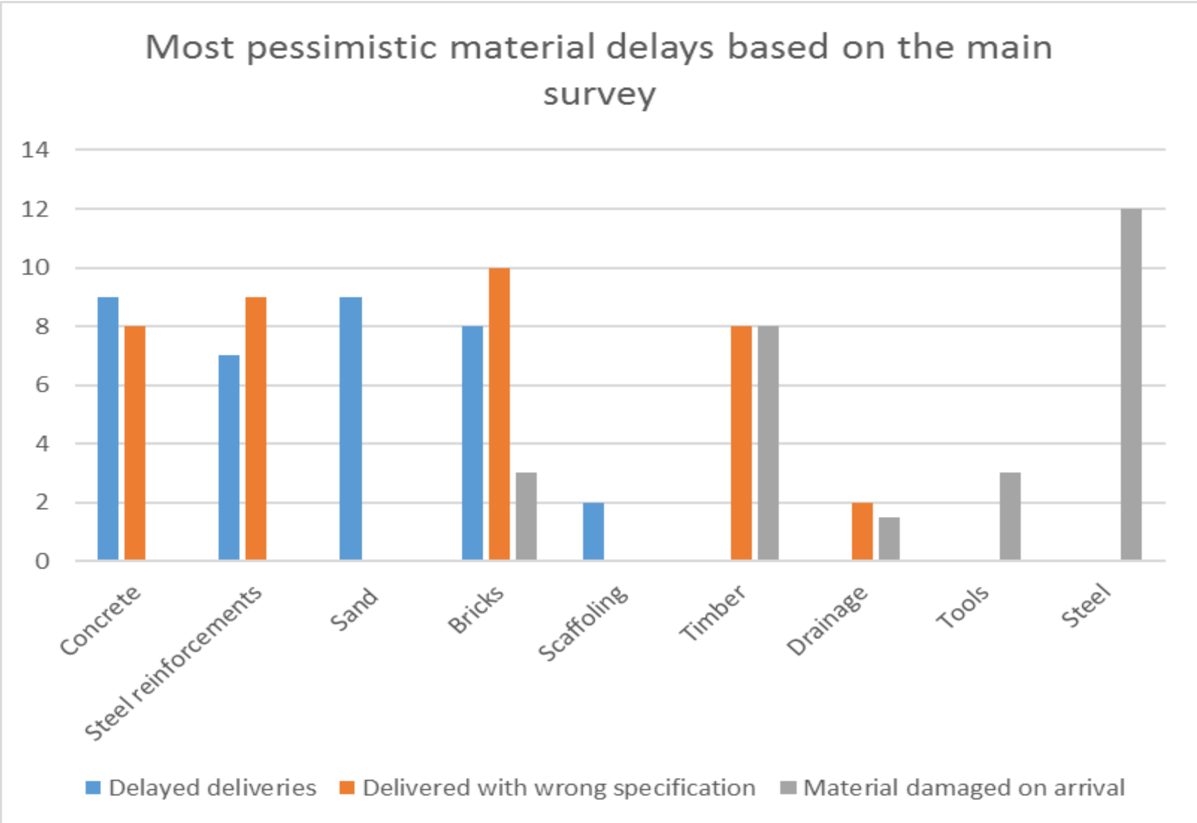


Figure 27 Most pessimistic material delays

3- Enhancing communication channels with suppliers

The use of information technology can help both suppliers and contractors to place an order, check it, trace it and pay for it. Using a shared system or application between suppliers and contractors can help them both to make sure that all information regarding orders is shared accurately between them and can help in avoiding any problems in orders. As an example, Electronic document management (EDM) is an information system that can be used.

6.2.2 Labour flow scenario

As discussed earlier in the investigation section and the main survey, the delays in labour flow are the result of shortage in skilled, semi-skilled and unskilled labourers.

Figure 28, presents some examples of the labour flow delays pessimistic scenario in the CPM network.

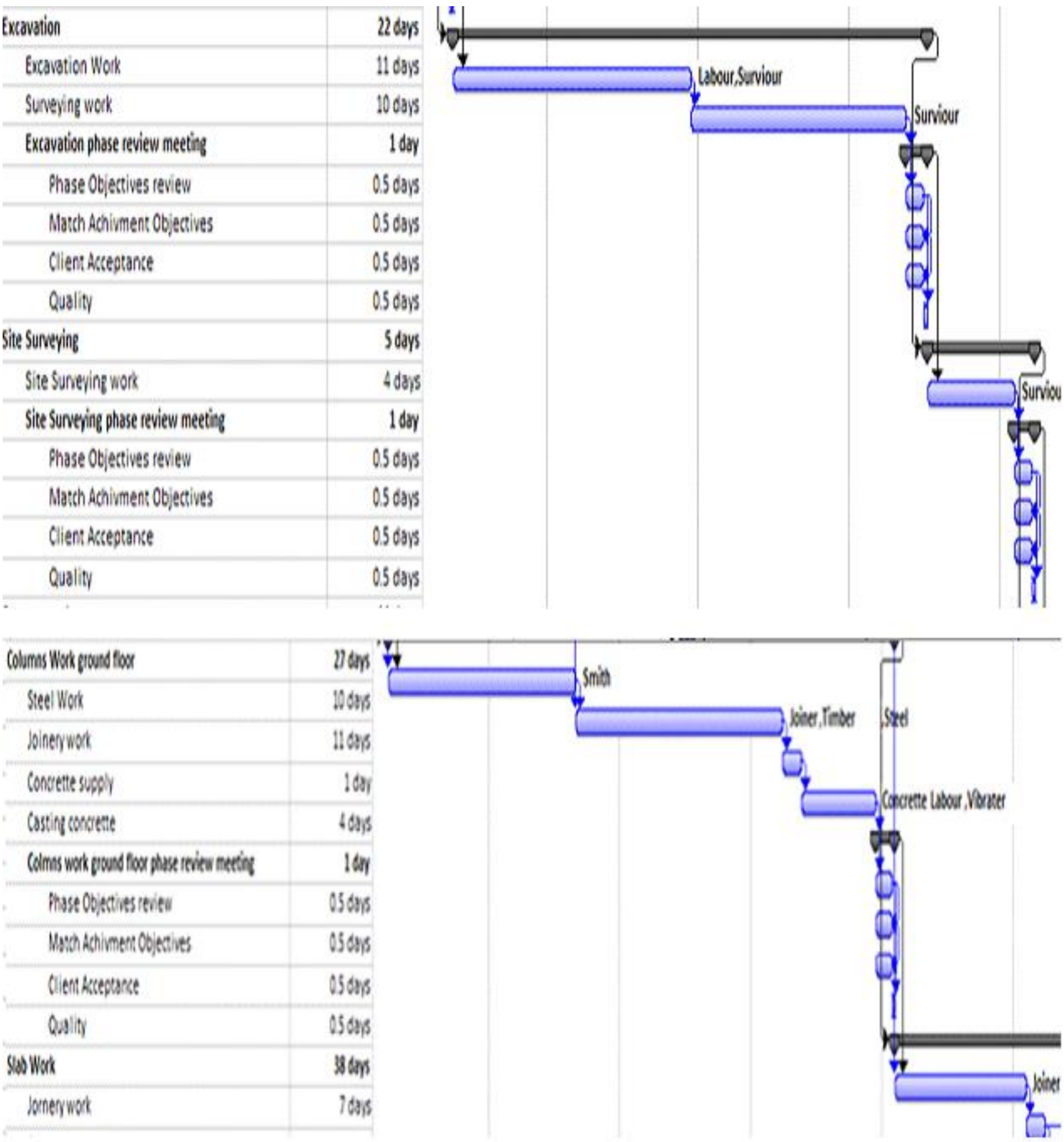


Figure 28 Labour flow delays scenario example

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5	138	0	0
Labour delay	1/1	19/9	263	125	90%

Table 29 Comparison of actual vs labour flow delays scenario

As can be seen from the simulation results in table 29, the project was delayed by 90% of its duration. That huge impact reveals the importance of managing the labour flow as it can lead to overrun costs and delays. Moreover, the results of the main survey suggest the average probability of the labour flow delay occurrence is 8.4%.

Labour flow				
Skill shortage	**Percentage**	**Delay**		
		Min	Most	Max
Electricians	9%	1	2	3
Plumbers	6%	1	1	2
Ground workers	16.4%	0.5	1	2
Surveyors	8.4%	1	3	4
Joiners	8%	1	1	5
Labourers	2.4%	1	2	3
Bricklayers	7%	1	2	3
Scaffolders	9%	4	5	7
Excavators and frame	8%	1	2	4
Compaction labourers	11%	4	8	9
Steel workers	7.4%	3	6	7

Table 30 Labour flow delays obtained from the main survey

The main survey results suggest that contractors in Jordan struggle to find ground workers and compaction labourers. Main contractors should find ways to attract labourers in the two professions in order to reduce the risk of having problems with labour flow, which may lead to delaying the whole project.

Managing labour flow in construction suffers from some serious problems such as: labour shortage, migration and low productivity. Dealing with labour flow problems is important but, can be complicated as it involves different factors. There are many implications of labour flow problems on projects. As an example, labour shortage main implication on a project is that some activities may need to be extended beyond their normal duration.

Other problems that may disrupt the labour flow in the construction industry are high risk environment and shortage in high skilled labour

Labour shortage and migration problems can be the main source of labour flow delays in Jordan, however, the following may give some possible solutions to the labour flow problems:

1- Opening training opportunities to low skilled labourers to become professional/qualified
2- More safety on sites may help to attract individuals to some highly skilled professions.
3- Hiring from other industries.
4- Encourage knowledge transfer between high skilled and other labourers

Skilled and semi-skilled labour shortage is a worldwide concern. Recently this issue has become a main challenge for the global construction industry as labour supply is below the demand in this industry. Local workforce participation is not very encouraging and it is recognised that vocational training programs for skilled labourers do not meet the needs of the construction industry as skilled labourers leave the construction industry due to many reasons in particular, safety issues. Therefore, labour shortage can disrupt the development in the construction industry and cause project delays. Moreover, the high demand of labourers in the construction industry and their low supply may result in an increase in their financial demands which consequently increases the cost and becomes a financial burden on both contractors and clients. (Zaki, Mohamed and Yosef, 2015)

According to Hillesund and Stave (2015), the Syrian refugees' influx impacted the Jordanian labour market by increasing the number of unskilled labourers which led to an increase in supply which exceeded the demand for this profession. Consequently, unskilled labour wages were lowered which influenced labourers to either migrate or shift to other industries looking for better earnings.

Dealing with labour flow problems is a real concern in the construction industry which plays a major role in the construction supply chain. Recent developments in the construction industry indicated that the use of robots in construction can be a solution. Using robots has already begun in some countries to control productivity and shortage in labour but still under development. (Acton, 2012)

6.2.3 Equipment flow scenario

As discussed earlier in the investigations section and the main survey, the delays in the equipment flow can be the result of loaning companies, unavailability and/or breakdowns.

Figure 29, presents some examples of the equipment flow delays pessimistic scenario in the CPM network..

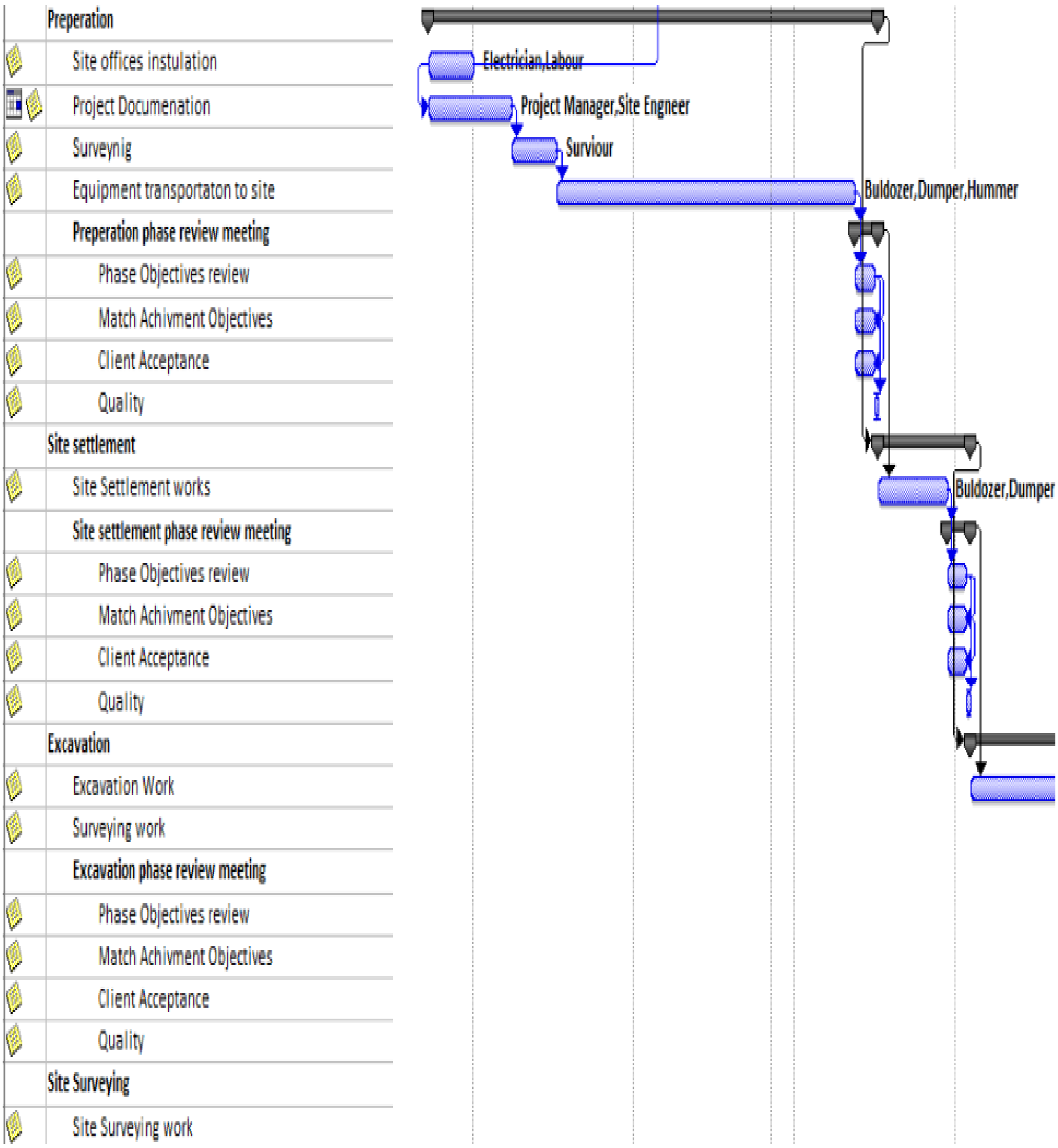


Figure 29 Equipment flow delays scenario

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5	138	0	0
Delay	1/1	20/5	141	3	2.2%

Table 31 Comparison of actual vs equipment flow delay scenario

As can be seen in the simulation results in table 31, the project was delayed by 2.2% of its duration which is equal to 3 days. As was stated earlier, a delay in an activity can lead to delays in other activities. Moreover, the results of the main survey suggest, the average probability of the equipment flow delays occurrence is 10%.

The following table 32 reveals the results of the main survey. The results indicated that hammers and cranes are the most common equipment that contractors have a problem to obtain in projects.

Equipment flow				
Equipment	**Percentage**	**Delay**		
		Min	Most	Max
Hammer	11%	2	6	12
Crane	9%	1	4	6

Table 32 Equipment flow delays obtained from the main survey

The lack of equipment impacts on projects performance as it was seen in the simulation scenario, as small to medium sized construction companies in general do not have the financial ability to purchase their own equipment. In order to deal with this problem, the majority have to rent equipment or sub contract the work. Both of these solutions may lead to other problems in regard to cost, availability, quality, control and time.

Moreover, Nagpal (2016) stated that, the major challenges facing the equipment flow are: undeveloped used equipment market, the lack of renting companies, the lack of qualified equipment handlers and the lack of fixed pricing to both rent or buy equipment.

According to Ross (2013), initiating partnerships with lending companies can be a solution for this problem as partnering may help to contractors gain access to equipment when needed and decrease the risk of having any difficulties with the equipment.

6.2.4 Information flow scenario

As discussed earlier in the main survey and the investigation section, information flow in this research deals with the information flow between the main contractor and the client. The client on that flow is responsible regarding delays due to any change in the design or time taken by the client to take a decision.

Figure 30, presents some examples of the information flow delays pessimistic scenario in the CPM network.

Figure 30 Information flow delays scenario example

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5	138	0	0
Information delays	1/1	26/5	147	9	6.5%

Table 33 Comparison of actual vs information flow delays scenario

As described earlier, the information delays in this research refer to the client and main contractor's communications and information flow between them. As can be seen from table 33, the information delay simulation scenario resulted in a 9-day delay which represented 6.5% of the total duration of the actual project. Based on the main survey findings, the average probability of information flow delay occurrence is 20%.

The results of the main survey suggested that the interactions between the client and the main contractor can be the main source of information delays. Clients change in orders interrupt the construction process as it can create a new job or break the work.

Moreover, sometimes obtaining the clients approval is essential before starting the next activity in the project; this can cause a delay for many reasons such as: the clients poor planning regarding job specifications, limited time by the client to review and accept the work or a financial constraint from the client's side.

Information flow				
Information	**Percentage**	**Delay**		
		Min	Most	Max
Payment	36%	0.5	1	1
Weekly Reports	4%	1	1	2

Table 34 Information flow delays obtained from the main survey

As can be seen in table 34, payments and weekly reports may disrupt the information flow between the client and the main contractor. Clients play a major role in the information flow as obtaining clients acceptance of works on a weekly basis is essential for the work to continue in a timely manner. Client's unavailability may disrupt the work by delaying some activities which require consent by the client or indeed payment from the client in order to continue.

Solving information flow problems is the duty of both the contractor and the client. Information delays can happen in any project, ways in which contractors may help in reducing the risk of information delays occurring are as follows:

1- Getting the client more familiar with the different aspects of the project

The contractor can help the client by educating him/her in the construction process, expectations, quality of work, time, etc. As the client may not have any knowledge about project management and the construction process, some projects documentation, graphs, tables and pictures may help the client understand the construction process and help the client in understanding the plan, design, quality and other issues related to the construction process.

2- Including the client in project meetings

Taking part, where applicable, in project meetings may help the client to become more involved during the construction process which can lead to increase the awareness of the client regarding the different aspects of the construction process, and the implications of any change in the project plan in terms of cost and time.

On the other hand, ways in which the client may help in reducing the risk of information delays occurring such as:

1- Be considerate, accessible, kind, approachable and follow the work schedule.

Following works schedule and meeting financial and consensual obligations on time, as stated in the contract, may help in avoiding work disruptions due to lack of contractors' funds or inability to carry out work without client consent.

2- Clear project specification.

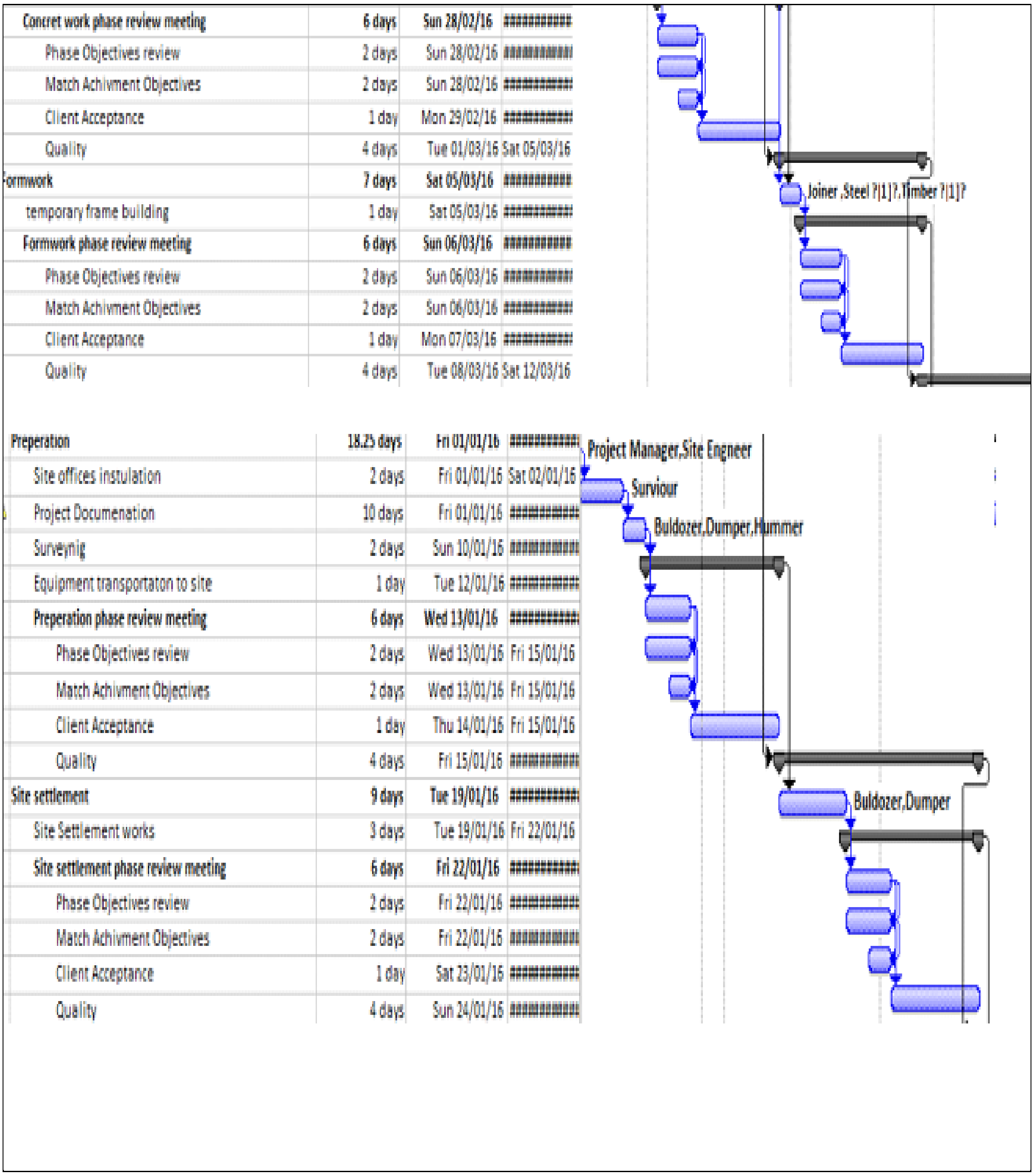
Clear and concise information relating to the project scope and specifications both at the initial stages and throughout the project may help in avoiding disputes. Defining a process to deal with project changes helps to reduce the risk on having a dispute or conflict should a design change occur.

To conclude, establishing good information flows ensures that the contractor understands the client's needs, specifications and concerns relating to the project. Ultimately, it is the client's responsibility to avoid causing any work disruptions.

6.2.5 Management information flow scenario

As discussed earlier, management information flow in this research refers to the information flow in the main contractor's company.

Figure 31, presents some examples of the management information flow delays pessimistic scenario in the CPM network.



Concret work phase review meeting	6 days	Sun 28/02/16	###########
Phase Objectives review	2 days	Sun 28/02/16	###########
Match Achivment Objectives	2 days	Sun 28/02/16	###########
Client Acceptance	1 day	Mon 29/02/16	###########
Quality	4 days	Tue 01/03/16	Sat 05/03/16
ormwork	7 days	Sat 05/03/16	###########
temporary frame building	1 day	Sat 05/03/16	###########
Formwork phase review meeting	6 days	Sun 06/03/16	###########
Phase Objectives review	2 days	Sun 06/03/16	###########
Match Achivment Objectives	2 days	Sun 06/03/16	###########
Client Acceptance	1 day	Mon 07/03/16	###########
Quality	4 days	Tue 08/03/16	Sat 12/03/16

Preperation	18.25 days	Fri 01/01/16	###########
Site offices instulation	2 days	Fri 01/01/16	Sat 02/01/16
Project Documenation	10 days	Fri 01/01/16	###########
Surveynig	2 days	Sun 10/01/16	###########
Equipment transportaton to site	1 day	Tue 12/01/16	###########
Preperation phase review meeting	6 days	Wed 13/01/16	###########
Phase Objectives review	2 days	Wed 13/01/16	Fri 15/01/16
Match Achivment Objectives	2 days	Wed 13/01/16	Fri 15/01/16
Client Acceptance	1 day	Thu 14/01/16	Fri 15/01/16
Quality	4 days	Fri 15/01/16	###########
Site settlement	9 days	Tue 19/01/16	###########
Site Settlement works	3 days	Tue 19/01/16	Fri 22/01/16
Site settlement phase review meeting	6 days	Fri 22/01/16	###########
Phase Objectives review	2 days	Fri 22/01/16	###########
Match Achivment Objectives	2 days	Fri 22/01/16	###########
Client Acceptance	1 day	Sat 23/01/16	###########
Quality	4 days	Sun 24/01/16	###########

Figure 31 Management information flow delays scenario example

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5/2015	138	0	0
Management Delay	1/1	15/3/2016	440	302	219%

Table 35 Comparison of actual vs management flow delays scenario

The information flows within the contractor's company had the highest impact on the project's performance, as the simulation scenarios suggest all management delays can result in delaying the project 219%. Based on the main survey findings, the average probability of management flow delay occurrence is 13.4%. This result indicates the importance of information flow in the contractor's company, regarding exchanging accurate information, at the right time and to the right person.

Moreover, management flow delays can be a main source of other flow delays for example, not providing the right information for materials purchase may lead to delays in the material flow.

Table 36 presents the results of the main survey. The results suggest that main contractors encounter some difficulties in managing information flow within their firms. The results also suggest that project documentation and phase reviews have the highest impact in terms of possible delays and probability of occurrence. Monitoring these activities, adopting corrective actions and improving them can help contractors to reduce the risk of having problems with information flow.

Management information flow				
Affected activities	**Percentage**	**Delay**		
		Min	**Most**	**Max**
Project documentation	24.9%	3	4	6
Objectives review	5%	0.5	1	1.5
Achievement objective	2%	0.5	1	1.5
Quality	15%	1	2	3.5
Client acceptance document	20%	0.5	0.5	0.5
Phase review	13.5%	1	2	5

Table 36 Management flow delays obtained from the main survey

The management information flow delays can happen for many reasons. Clarkson and Eckert (2010) contributed that some of the major problems that can be resulted from construction firm's failure in transmitting information such as:

1- Team members lack of awareness of the way tasks needs to be done

Failing to understand the designer's requirements for each task may results in time delays and additional costs.

2- Team members lack of awareness of information application process

Failure to understand how the overall project relies on all team members' contributions may result in disturbing the information exchange process between team members, designers and management

3- Lack of awareness of change in design and processes

Design changes and tasks rescheduling can happen occasionally in construction projects, any delay in passing the new information to team members may result in additional delays and costs.

4- Expertise of intermediary

The lack of technical knowledge from people that needs to pass information within the company may result in a failure in understanding the implications of the information. For example: projects presentations to clients or the board of directors are frequently made by financial experts or mangers with low technical understanding.

As discussed in this section, enhancing the communication channels in construction companies' intranets in the Jordanian industry helps in reducing the risk of running behind schedules. According to Pourrostam and Ismail (2012), the use of technology in construction projects helps companies to enhance their communication channels and to transmit accurate and timely information that results in getting accurate information regarding the project. The use of information technology can help in facilitating the process of transferring accurate information within the construction supply chain and in particular, the contractor's companies. Electronic document management (EDM), web based information systems and application service providers (ASP), are all examples of possible solutions to enhance the information flow in construction companies in site and offices.

6.2.6 All supply chain flows scenario

Figure 32, presents some examples of the construction supply chain (all supply chain) delays pessimistic scenario in the CPM network.

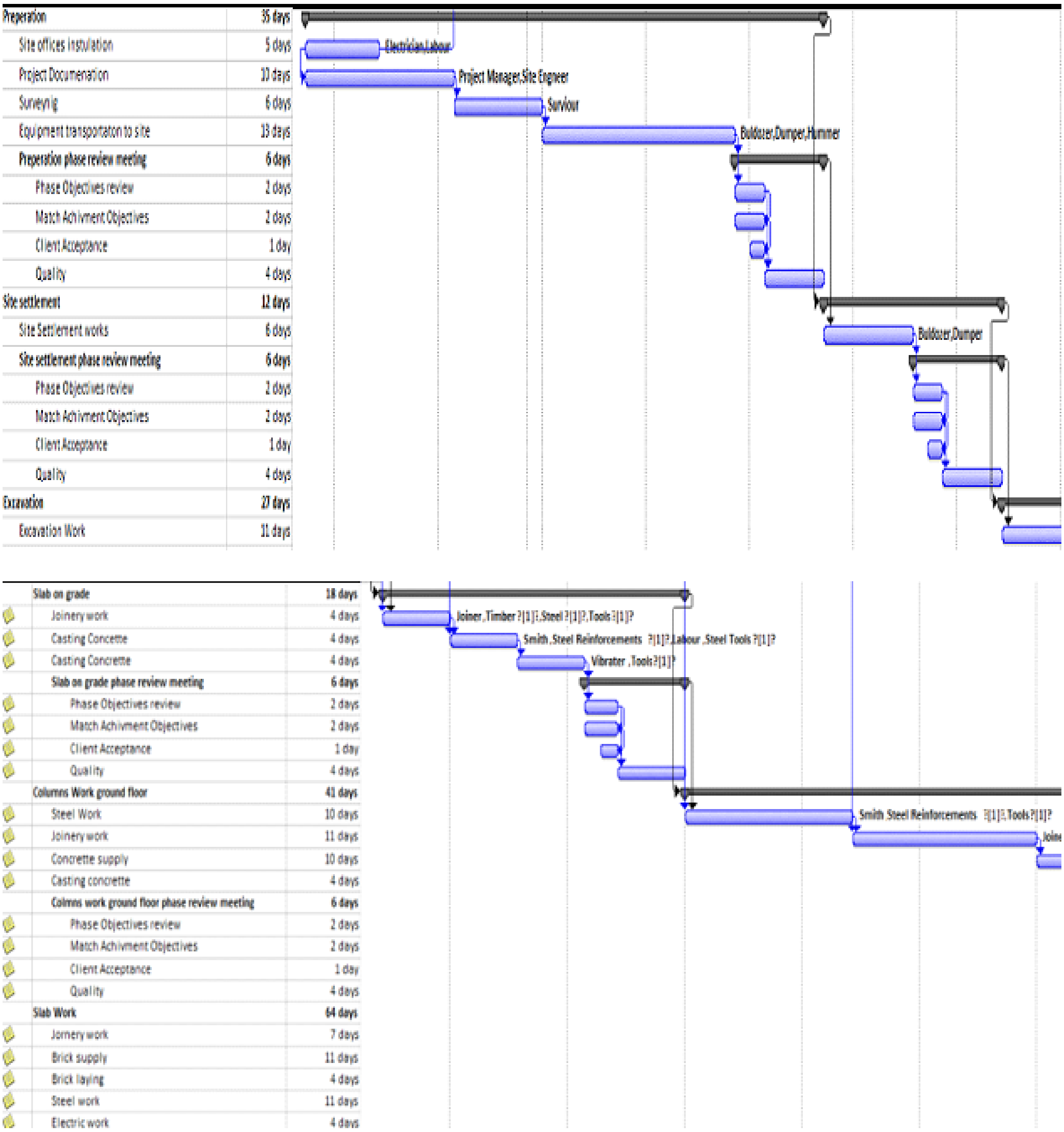


Figure 32 All supply chain flows delays scenario example

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Actual	1/1	17/5	138	0	0
Construction supply chain delays	1/1	26/3/2016	451	313	227%

Table 37 Comparison of actual vs all supply chain flow delays scenario

As can be seen from table 37, the results of the simulation scenario of all supply chain delays that happen together has delayed the project by 227%. Based on the main survey findings, the average probability all supply chain delays occurring at the same time is 12.2%.

This massive delay in the project duration indicates some serious difficulties that companies may encounter should they fail to monitor, manage and control its supply chain. This research analysed supply chain management impact on residential construction projects in terms of time, and to what extent it may impact residential housing projects in the Jordanian industry. Furthermore, it can be argued that this research is one of the first attempts to quantify the impact of the construction supply chain flows components separately. Although, it can be concluded that delays in time contribute to additional costs which can open an opportunity for further research.

6.2.7 Summary

Supply chain management is an important topic that revealed the importance in both construction and manufacturing industries. Based on the analysis of supply chain delays, it can be contributed that managing construction supply chains is vital and, one of the main success factors for projects as it helps in decreasing time, cost and reduce the risk of encountering project delays and offers more control over project performance parameters.

Table 38 and figure 33 on the following page summarise the findings from the simulation scenario based on the highest impact on the project duration.

Scenario	Start	Finish	Duration in days	Delay in days	Delay percentage
Construction supply chain delays	1/1	26/3/2016	451	313	227%
Management delay	1/1	15/3/2016	440	302	219%
Labour delay	1/1	19/9	263	125	90%
Material delay	1/1	25/7	207	69	50%
Information delay	1/1	26/5	147	9	6.5%
Equipment delay	1/1	20/5	141	3	2.2%
Actual	1/1	17/5	138	0	0

Table 38 All supply chain flow delays obtained from the main survey

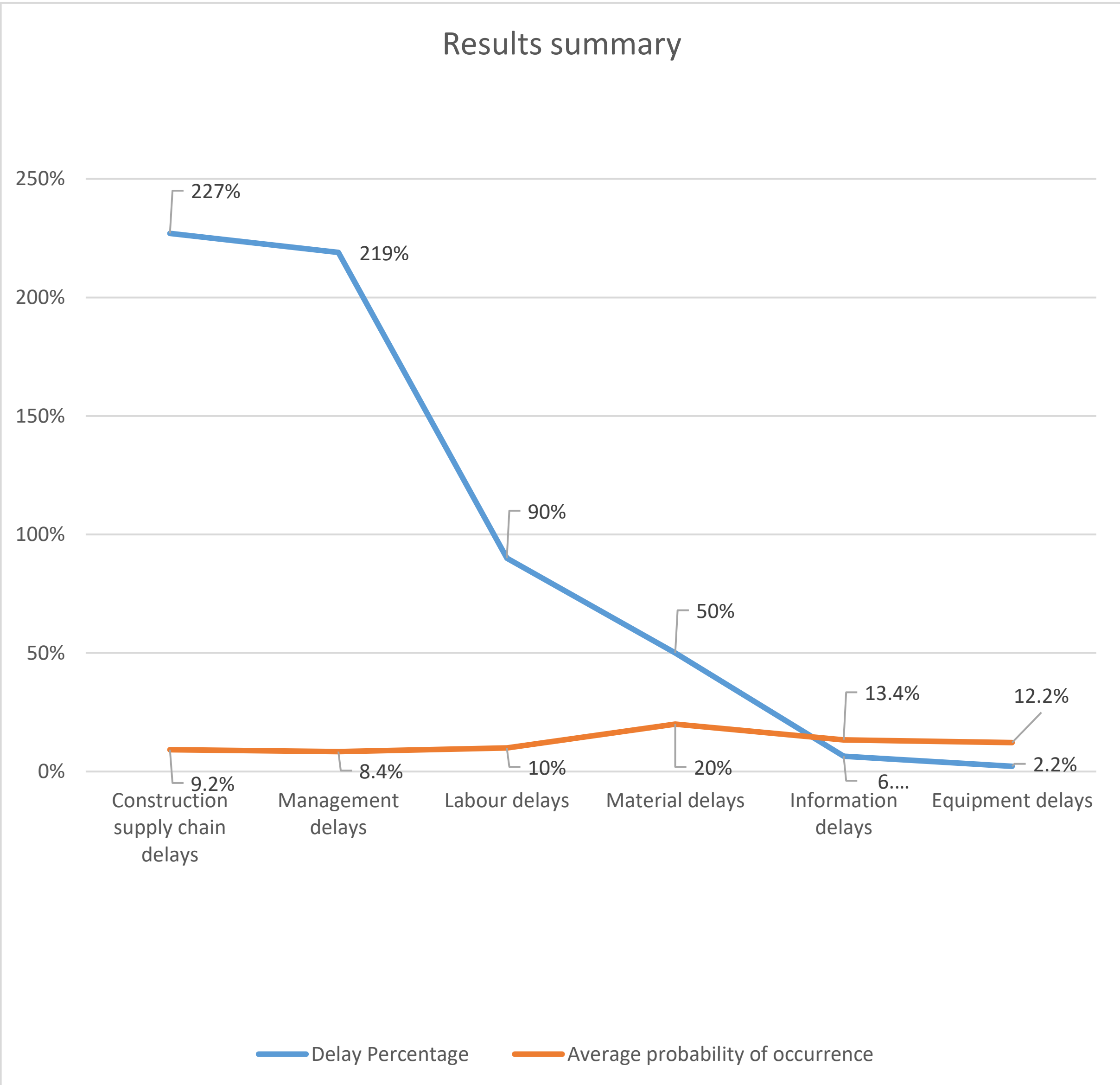


Figure 33 Results summary

6.3 Implications of the results

In theory, the provision of time buffers is a means of absorbing flow delays by way of adding time to the estimated time of a project in order to keep the project on track. Materials, for example, would be ordered and delivered on site in advance of the activity that will use them. The reasoning behind this is, should there be an unexpected delay in the delivery of the materials, the activity will start on time and the project will remain on track. Factors should be taken into account when providing time buffers such as, which of the activities are most likely to delay the project; materials are use in various activities and delays can be likely. The availability of space for deliveries as storage issues could be another concern, and indeed cash flow implications.

Arguably this research is the first attempt to quantify to what extent construction supply chain flows may impact projects performance in terms of time.

Management information flow delays, information flow in the main contractor’s company, caused the greatest impact on project performance according to this research. The simulation scenarios suggested, management delays may result in delaying the project overall by 219%. The average probability of the occurrence of a management flow delay is 13.4%; based on findings in the main survey. Project documentation delays resulted in having the highest impact with 24.9% probability of occurrence, a 6-day delay on the activity’s duration. Careful monitoring and corrective actions are necessary in order to lower the risk of encountering future problems. This was followed by phase reviews which amounted to a 13.5% probability of occurrence, a 5-day delay on the activity’s duration. The above indicate the importance of timely, accurate information flow in the main contractor’s company and indeed to the right person. Clearly, as the results suggest, main contractors are faced with difficulties in their firms, especially in relation to information flow and these problems can be the main cause of other flow delays. These issues could be due to many factors as previously stated; team members failing to understand the designer’s requirements for tasks, team members lack of understanding that projects rely on ‘all’ team members, failure to pass on new information regarding changes or rescheduling, lack of technical expertise when passing on information. Therefore, in an attempt to overcome or decrease the risk of schedule delays, training in and use of technology

Labour ranked second regarding impact on project performance delaying the project by 90% according to the simulation results table, with an average probability of occurrence of 8.4%.

Ground workers caused the highest impact with a 16.4% probability of occurrence, a 2-day delay on the activity's duration, followed by compaction workers with a probability of occurrence of 11%, a 9-delay on the duration, electricians and scaffolders resulting in 9% probability of occurrence, a 3-day and 7-day delay on duration respectively. The main survey revealed that there is difficulty finding ground workers and compaction workers. This appears to be the situation in Jordan and main contractors need to overcome this problem by possibly trying new ways to attract such labourers. There can be many reasons for labour shortage as labour skills themselves are indeed varied; skilled, semi-skilled and unskilled. Leaving this issue unresolved increases, the risk of labour delays which ultimately affects the extent of delay on the whole project. As discussed previously, labour migration is an issue. This could be true in the Middle East where conflicts are occurring. Shortage in high skilled labour is another area of concern, this could be overcome by training and investment in order to increase productivity and decrease potential delays.

Both the main survey and the investigations revealed that material flow delays, which ranked third regarding impact on projects performance, are caused mainly by 3 types of delays; late delivery, wrong specification and material damaged on site. The highest impact regarding late deliveries was scaffolding with a 16% probability of occurrence, a 2-day delay on the activity's duration. Concrete ranked highest regarding wrong specification with a 19% probability of occurrence, an 8-day delay the activity's duration. Regarding materials damaged on site, bricks ranked highest with a 9% probability of occurrence, a 3-day delay on the duration. The simulation results table exhibited a delay of 50% on the projects duration and a probability of a delay occurring is 9.2%. Material flow delays inevitably affect costs and impact hugely other activities therefore; it is vital to address such issues. A good contractor/supplier relationship may help overcome some problems, especially in the early stages of the project. This could help to inform the supplier as to the material specification and quantity well in advance of requiring the material. Managing the material whilst on site is another area of concern and was a cause of damage to material and/or lost/stolen material. These issues lead to a shortage which in turn causes delays and indeed has cost implications.

Information flow, that is communication between the 'client' and main contractor ranked fourth regarding impact on project performance. The simulation results table exhibited a delay of 6.5% on the projects duration with a 20% average probability of a delay occurring. The main issues were payment from the client to the main contractor for design changes with a probability of occurrence of 36%, a 1-day delay on the duration. Communication or lack of, between the two parties was also a problem. Clients often ‘change their minds’, and request a design alteration which interrupt or break works. Furthermore, clients require time to make a decision which is another cause of delay. Client’s approval is necessary in order to continue to the next stage of a project but clients are not always capable due to lack of proper knowledge and/or insufficient funding to approve. Risks relating to information delays may be reduced by familiarising the client with various aspects of the project. Including the client when project meetings take place would enable client awareness of the construction processes involved in the project. This inclusion may help the client to realise the implications of design changes regarding time delays and how that would have an effect on the overall cost.

The least impact on delays was equipment flow delays. The most likely causes are barriers with loaning companies, breakdowns and/or unavailability. The simulation revealed a delay in the duration of the project by 2.2%, equal to 3 days and the probability of the equipment flow delay occurring is 10%. Obtaining equipment is a common problem in particular hammers with a 11% probability of occurrence, a 12-day delay and cranes. This issue affects small to medium sized construction companies. Where financing equipment is not an option, they result to renting equipment or sub-contracting the work, which could result in additional costs, have time implications or the equipment may not be available. To overcome this problem and decrease risk, construction companies could begin partnerships with lending companies.

This research presented an analysis of the highest extent that each flow in the construction supply chain may impact residential housing projects performance in Jordan. In real life delays do not occur separately and/or to the highest extent. The results of this research are influenced by the iterations of the construction supply chain flows in the critical path network. The iterations influenced the results to be shifted either over estimated or under estimated i.e. the more iterations per activity means more repetitions of the activity’s delay which results in over estimation.

To conclude, providing time buffers to activities may enable the activities to absorb possible delays and decrease the risk of falling behind schedule which in turn may cause additional costs. It should be noted that time buffers should be added to activities with a high probability of occurrence and long delays in order to benefit of their use.

6.4 Understanding the results

As discussed in chapter 5, the critical path network used in developing the simulation scenarios was obtained from one of the sites visited. The critical path network (CPM) represented the skeleton level of a medium size residential housing project which is considered as a typical residential housing project in Jordan. The critical path network of that project consists of 18 activities and 140 sub-activities. Each sub-activity is related to a flow in the construction supply chain. The iteration of sub-activities in the critical path network influenced the results to be overestimated or underestimated depending on how many times the iteration appeared in the simulation and therefore, the amount of delays per related flow have been calculated. For example: material flow related activities iteration in the critical path network appeared 11 times, meaning the 11 iterations resulted in 69 days of delay (based on the findings), which equates to 6.27 days of delay per material flow activity.

Calculating the impact of each activity within the construction supply chain can help contractors and clients in planning and estimating the highest impact of any delay in any flow in the construction supply chain as it happens during the project and therefore, reschedule activities or take corrective actions to reduce the risk of running behind schedule. The following table, illustrates the iterations per construction supply chain flow activity and their impact on project duration delays per activity.

Construction supply chain flow	Iteration	Delay in days	Activity delay per day
Information	12	9	0.75
Management information	80	302	3.775
Material	11	69	6.27
Labour	36	125	3.472
Equipment	1	3	3

Table 39 Construction supply chain flows iteration

6.5 supply chain management integration in the Jordanian construction industry

In order to reduce the impact of the delays as outlined before in this chapter, an efficient process of effective integration of supply chain management in the Jordanian construction industry is necessary to progress and develop the industry. To facilitate the improvements a number of issues need to be addressed. Firstly, a shift from the selection of contractors based on lowest bid to selection based on best value. Secondly, a shift from contractor/client orientated relationship to involve all parties within the supply chain and thirdly, a shift from a disbanded project team on completion of a project to a continuation of the supply chain relationships in new projects.

It is vital to remove the deep-seated barriers of traditional relationships within the construction industry and replace it by introducing a 'change management framework', at operational level, in order to implement supply chain management.

Supply chain integration aids to the efficiency and stream-lines the objectives of all parties involved helping to achieve goal congruence, productivity and the minimisation of waste.

To implement supply chain integration, a shift from the traditional contractual framework, the integration of organisational processes regarding all participants together with long term commitment and trust.

The integration process of supply chain management would benefit the client regarding the overall delivery of the final project but moreover, increased profit margins, decreased aggravation and stress, development of both a no-blame culture, mutual understanding and the attainment of enhanced reputations for the contractor.

It is essential to have a suitable culture for the integration and collaboration of the supply chain within the construction industry which consists of the following elements: internal and external trust, mutual benefits, transparent exchange of information within the supply chain, high quality of information and transparency of information, good understanding and communication between all parties, goal congruence and corporate emphasis on supply chain management.

The Jordanian industry should make corrective actions to allow the efficient supply chain integration to take place such as: early involvement of all parties, education of project staff, fair payment, have knowledge of the benefits of integration, be familiar with and have an understanding of new contractual documents. Should all parties within the supply chain be targeted, including the main contractor, subcontractor and suppliers, overall costs of construction would reduce. In addition, subcontractor and supplier early involvement is as necessary as early contractor involvement. This early involvement of all parties would allow the exchange of expertise which may help to reduce costs furthermore, early involvement integration would enable suppliers to be service providers as oppose to providers of products.

Chapter 7

Conclusion and recommendations

This chapter will provide the conclusion of this research and some recommendations for the construction industry in Jordan and to further researchers as follows:

7.1 Conclusion: this section provides the conclusion of this research based on the findings.

7.2 Construction industry recommendations: this section provides recommendations for the construction industry in Jordan that can help in reducing the risk of having supply chain delays in projects

7.3 Further research recommendations: this section provides research opportunities to be carried out in future

7.1 Conclusion

Below are the conclusions from the research which derive from the results of simulation models with some simplifications such as: there was no rescheduling of the project allowed and it was assumed that all delays were independent. The following conclusions can be made, (provided the above simplifications are acceptable). Note: The actual estimated duration of the project was 138 days.

1. The management information flow delays resulted in increasing the project duration to 440 days which equates to 302 days of delay and represents 219% of the initial estimated duration. Based on the main survey, the average probability of occurrence was 13.4%. This flow represented the highest impact regarding project performance delays which, reveals the importance of establishing clear communication channels between the employees and decision makers within a company. Exchanging accurate information at the right time, to the right person, may help avoid information disruptions that lead to a disruption in the project.

2. Labour flow delays resulted in increasing the project duration to 263 days which equates to 125 days of delay and represents 90% of the initial estimated duration. Based on the main survey the average probability of occurrence was 8.4%. This delay may be due to the current crisis in the Middle East as many labourers have migrated to the Gulf in order to find employment.

3. The material flow delays resulted in increasing the project duration to 207 days which equates to 69 days of delay and represents 50% of the initial estimated duration. Based on the main survey the average probability of occurrence was 9.2%. Other factors which are not taken into consideration are: the complexity and extent of the particular construction or the types of materials used on the project and many other possible factors.

4. Information flow delays resulted in increasing the project duration to 147 days which equates to 9 days of delay and represents 6.5% of the initial estimated duration. Based on the main survey the average probability of occurrence was 20%.

5. Equipment flow delays resulted in increasing the project duration to 141 days which equates to 3 days of delay and represents 2.2% of the initial estimated duration. Based on the main survey the average probability of occurrence was 10%.

6. All construction supply chain flows combined increased the project duration to days which equates to 312 days of delay and represents 227% of the initial estimated duration. Based on the main survey the average probability of occurrence was 12.2%.

7. Within the simulation scenario development process, the pessimistic version was prepared. The pessimistic version, where the logic allowed, was positioned in series. The highest pessimistic value was provided to the associated activity of each delay. This was selected in order to analyse to what extent supply chain management can impact project performance.

Table 38 and figure 33 in Chapter 6 represented a summary of the research findings from the analysis chapter with the average probability of each delays occurrence based on the main survey results.

The Jordanian industry should make corrective actions to allow the efficient supply chain integration to take place such as: early involvement of all parties, education of project staff, fair payment, have knowledge of the benefits of integration, be familiar with and have an understanding of new contractual documents. Should all parties within the supply chain be targeted, including the main contractor, subcontractor and suppliers, overall costs of construction would reduce. In addition, subcontractor and supplier early involvement is as necessary as early contractor involvement. This early involvement of all parties would allow the exchange of expertise which may help to reduce costs furthermore, early involvement integration would enable suppliers to be service providers as oppose to providers of products.

7.2 Construction industry recommendations

1. Evidently, various versions may be produced in an attempt to quantify the impact of supply chain delays on various projects within the industry. Doing so could enable contractors to isolate and concentrate on these delay sources. Indeed, the participants of projects could benefit from these results of research in order to inform themselves in decision making and management of future projects.

2. Early supplier involvement with the contractor, in the design phase, can aid both parties to determine the right material, its availability and decrease the risks of having additional delays. It is a well-known fact that early involvement of contractors is beneficial and their positive impact proves to be successful in projects. The contractor's main influence is their competency regarding buildability and knowledge of material options; this research supports this early involvement option by the identification and quantification of material delays being caused by material sourcing.

3. Labour flow, as stated in the research, ranked second in delays. Issues such as a shortage in skilled labour can potentially be overcome if the government were to facilitate the work permit procedure in order to attract migrant workers and utilise their varied skills. Additionally, prefabricated materials may merit consideration. Prefabricated materials, arguably, decreases contractors' dependency on those skills that prove difficult to provide for within the construction industry such as, aluminium outer sections (prefabricated) can be erected reducing the dependency on builders, which would ultimately have an impact on time management.
4. Incorporating time buffers into a project may have valuable implications relating to both time and cost. In essence, time buffers make provisions for delays by having resources on site prior to their required time of use. These time buffers are typically used where there is an expected delay such as; difficult to source materials. Therefore, activities which are likely to have problems benefit most from time buffers. Moreover, applying time buffers to activities in the CPM network may help contractors to observe possible delays and therefore reduce the risk of potential delays.

7.3 Further research recommendations

1. Further research relating to the implications of cost and quality within supply chain delays could be developed. The main cost is a result of the main contractor's costs. These costs are incurred by the additional time required by the main contractor, spending time on site as a result of delays. Liquidated damages may also be payable. It should be noted that information flow delays are the employer's responsibility and therefore, are unlikely to be part of the costs relating to the main contractor.

2. Simulations were carried out using data and simulation scenarios relating to small/medium residential housing building projects. The question arises to the usefulness of applying these models to other projects. This may be carried out using different CPM networks and making modifications to the types of delays and indeed number of delays, which occur in various projects. For example, where large quantities of material exist but a lack of types of material, modifications can be made suitable to the characteristics of the project.

3. Information flow delays are another cause of concern. One activity may be delayed as a result of varying information flow delays and the effect of these delays on a project could vary considerably. Delays such as obtaining specifications from either the client or architect, getting planning permissions or permissions from local authorities would have varying effects on the overall project. This are could be examined more thoroughly.

4. Simulation models assume that supply chain delays are independent however, delays that are dependent exist i.e. one delay can be the result of another delay. This issue should be accounted for in future models.

5. Rescheduling activities is a usual/regular activity on projects however, this model does not allow for this. It is recommended that future versions include rescheduling in order to present simulation models in a more realistic context.

6. The results derived were from scenarios of potential delays within the supply chain on a CPM network. There are varied types of delays in reality, not only supply chain delays but provided these non-supply chain delays are not included in the project, comparisons in total delays could be made to validate the results of this research.

References

(2007) 'Council of Logistics management (CLM)', www. clm1. org.

Acton, Q.A, 2012. Advances in risk and prevention research and treatment. 1st ed. Georgia: Scholarly Editions.

Agapiou, A., Flanagan, R., Norman, G. and Notman, D. (1998) 'The changing role of builders’ merchants in the construction supply chain', Construction Management and Economics, 16, pp. 351-361.

Akintoye, A.; McIntosh, G. and Fitzgerald, E. (2000), ‘A survey of supply chain collaboration and management in the UK construction industry’, European Journal of Purchasing and Supply Management, Vol. 6, 2000, pp. 159 – 168.

Al-Khalil, M., Assaf, S., Al-Faraj, T. and Al-Darweesh, A. (2004) 'Measuring Effectiveness of Materials Management for Industrial Projects', Journal of Management in Engineering (ASCE), 20, (3).

Al-Momani, A. H. (2000) 'Construction delay: a quantitative analysis', International Journal of Project Management, 18, pp. 51-59.

Al-Rifai and Amoudi , J. O, 2015. Understanding the Key Factors of Construction Waste in Jordan.*Jordan Journal of Civil Engineering*, [Online]. 10, 244-254. Available at:https://www.researchgate.net/publication/300020159_Understanding_the_Key_Factors_of_Construction_Waste_in_Jordan[Accessed 24 March 2016].

Alinaitwe, Apolot and Tindiwensi, H, R, D, 2013. Investigation into the Causes of Delays and Cost Overruns in Uganda's Public Sector Construction Projects. Journal of Construction in Developing Countries, 18(2), 33–47.

Ammar, M. A. and Mohieldin, Y. A. (2002) 'Resource constrained project scheduling using simulation', Construction Management and Economics, 20, pp. 323-330.

Amit Nagpal. 2016. *Construction equipment industry: Challenges, trends & future roadmap*. [ONLINE] Available at: http://realty.economictimes.indiatimes.com/realty-check/construction-equipment-industry-challenges-trends-future-roadmap/1157. [Accessed 2 May 2016].

Arnold, J. R. T. (1991) Introduction to materials management. London: Prentice-Hall International (UK) Limited.

Averill Law, 2014. Simulation Modeling and Analysis (McGraw-Hill Series in Industrial Engineering and Management). 5 Edition. McGraw-Hill Education.

Baldry, D. (1996) 'Client benchmarking of contractor performance', in Langford, D. A. and Retik, A. (eds) The organization and management of construction: Shaping theory and practice. Vol. 2E& FN Spon.

Ballard, G. and Howell, G. (2001) 'What kind of production is construction? ' in Proceeding IGLC.

Bank Audi; (2015). “Jordan Economic Report.” Bank Audi sal Group, Lebanon. P.2-4

Banwell, G. H. (1964) The Banwell report. HMSO.

Barratt, M. (2004), ‘Understanding the meaning of collaboration in the supply chain’, Supply Chain Management: An International Journal, Vol. 9, No. 1, 2004, pp. 30 – 42.

Beamon, B. M. (2002) 'Measuring supply chain performance', International Journal of Operations & Production Management, 19, (3), pp. 275-292.

Berry, D., Towill, D. R. and Wadsley, N. (1994) 'Supply chain management in the electronics product industry', International Journal of Physical Distribution & Logistics Management, 24, (10), pp. 20-32.

Bhatnagar, R. and Sohal, A. S. (2004) 'Supply chain competitiveness: measuring the impact of location factors, uncertainty and manufacturing practices', Article in Press, Technovation, xx, (xxx-xxx), pp. 1-14.

Bolstorff and Rosenbaum, P, R, 2012. Supply Chain Excellence: A Handbook for Dramatic Improvement Using the SCOR model. 3rd ed. New York: AMA.

Bresnen, M. J. and Marshall, N. (1999) 'Partnering in construction: a critical review of issues, problems and dilemmas', Construction Management and Economics, 18, pp. 229-237.

Briscoe, G., Dainty, A. R. J. and Millett, S. (2001) 'Construction supply chain partnerships: skills, knowledge and attitudinal requirements', European Journal of Purchasing & Supply Management, 7, pp. 243-255.

Briscoe, G. H., Dainty, A. R. J., Millett, S. J. and Neale, R. H. (2004) 'Client-led strategies for construction supply chain improvement', Construction Management and Economics, 22, (February), pp. 193-201.

Christopher, M. (1992) Logistics and supply chain management: strategies for reducing costs and improving service. London, UK: Pitman Publishing.

Chung, C. A. (2004) Simulation modelling handbook: A practical approach. CRC Press.

Clarkson and Eckert, J and C, 2010. Design Process Improvement: A review of current practice. 1st ed. New York: Springer.

Cohen, M. A. and Lee, H. L. (1990) 'Out of touch with customer needs? Spare parts and after sales service. ' Sloan Management Review, 31, (2), pp. 56-66.

Collis and Hussey, J and R, 2009. Business Research: A Practical Guide for Undergraduate and Postgraduate Students. 3rd ed. London: Palgrave Macmillan.

Collis, J. and Hussey, R. (2013) Business research. A practical guide for undergraduate and postgraduate students. Palgrave Macmillan.

Cox, A. and Ireland, P. (2002) 'Managing construction supply chains: the common sense approach', Engineering, Construction and Architectural Management, 9, (5/6), pp. 409-418.

Cox, A. and Townsend, M. (2006) Managing in construction supply chains and market. London: Thomas Telford.

Courtney, R (1999), "CIB Agenda 21 and the building research community", Building Research & Information, 27(6), pages 373-377.

Creswell, J. W. (2003) Research design: Qualitative, quantitative and mixed methods approaches. Thousand Oaks, California: Sage Publication, Inc.

Croom, S., Romano, P. and Giannakis, M. (2000) 'Supply chain management; an analytical framework for critical literature review', European Journal of Purchasing & Supply Management, 6, pp. 67-83.

Dainty, A. R. J.; Briscoe, G. H. and Millett, S. (2001a), 'Subcontractor perspective of supply chain alliances', Construction Management and Economics, Vol. 19, 2001, pp. 841 –848.

Dainty, A. R. J.; Briscoe, G. H. and Millett, S. (2001b), 'New perspectives on construction supply chain integration', Supply Chain Management: An International Journal, Vol.6, No. 4, 2001, pp. 163 – 173.

Dave and Koskela, B, L, 2009. Collaborative knowledge management—A construction case study.Automation in Construction, Volume 18, Issue 7, 894–902.

David Frederick Ross, 2013. Competing Through Supply Chain Management: Creating Market-Winning Strategies Through Supply Chain Partnerships. 1998 Edition. Springer.

Davis, T. (1993) 'Effective supply chain management, ' Sloan management review, 34, (4), pp. 35-46.

De Muth, J, 2014. Basic Statistics and Pharmaceutical Statistical Applications. 3rd ed. London : CRS group

Denzin, N. K. (1970) The research act: A theoretical introduction to sociological method. Chicago: Aldine.

Dillman, D. A. (2011)'The design and administration of mail surveys', Annual Review of Sociology, 17, pp. 225-249.

Dornfeld, D , 2012. *Green Manufacturing: Fundamentals and Applications (Green Energy and Technology)*. 1st ed. California: Springer

Donyavi, S. and Flanagan, R. (2009) The impact of effective material management on construction site performance for small and medium sized construction enterprises. In:

Dainty, A.R.J. (Ed) Procs 25th Annual ARCOM Conference, 7-9 September 2009, Nottingham, UK, Association of Researchers in Construction Management, 11-20.

Easterby-Smith, M., Thorpe, R. and Lowe, A. (1991) Management Research: an Introduction. London: Sage.

Edum-Fotwe, F. T., Thorpe, A. and McCaffer, R. (2001) 'Organisational relationships within the construction supply-chain, in Proceedings of a Joint CIB Triennial Symposium. Cape Town:

Elaine Marmel, 2011. Microsoft Project 2007 Bible. 1 Edition. Wiley.

Elfving, J. A. (2003) Exploration of opportunities to reduce lead times for engineered-to-order-products. Unpublished PHD thesis. University of California.

Ellram, L. M. (1991) 'Supply chain management: the industrial organization perspective', International journal of physical distribution and logistics management, 21, (1), pp. 13-22.

Enshassia, Kumaraswamy and Al-Najjar, A, M, J, 2010. Significant Factors Causing Time and Cost Overruns in Construction Projects in the Gaza Strip: Contractors' Perspective. *International Journal of Construction Management*, 10, 35-60.

Eric Stallsworth. 2009. review of Microsoft Office Project 2007. [ONLINE] Available at:http://www.brighthubpm.com/software-reviews-tips/4148-managing-projects-with-microsoft-office-project-2007-part-three/. [Accessed 24 December 15]

Formoso, C. T. and Revelo, V. H. (1996) 'Improving the material supply system in small sized building firms', in Langford, D. A. and Retik, A. (eds) The organization and management of construction: shaping theory and practice. Vol. 1 London, UK: E & FN Spon, pp 229-238.

Frimpong, Y. and Oluwoye, J. (2003) 'Significant factors causing delay and overruns in construction of groundwater projects in Ghana', Journal of Construction Research, 4, (2), pp. 175-187.

Gameson, R. N. (2001) 'Client-professional communication during the early stages of project development', in Langford, D. A. and Retik, A. (eds) The organization and management of construction: Shaping theory and practice. Vol. 2E&F Spon.

Ghurka, N. (2003) Implementing supply chain "Best Practice" in the construction value system. thesis. MIT.

Greenwood, D. J. (2001) 'Subcontract procurement: are relationships changing? ' Construction Management and Economics, 19, pp. 5-7.

Greenwood, D. J. (2004) 'The North Tyneside Partnering Agreement: a study of Strategic Partnering in the Public Sector. Research Report carried out for the

Department of Trade and Industry by Northumbria University'.

Greenwood, D. J. (2005) 'Partnering Approaches and Supply Chain Relations', Construction Information Quarterly, Chartered Institute of Building, Ascot, 7, (1), pp. 3-5.

Gunasekaran, A., Patel, C. and McGaughey, R. E. (2004) 'A framework for supply chain performance measurement', International Journal of Production Economics, 87, pp. 333-347.

Hall, M. (2001), 'Root cause analysis: a tool for closer supply chain integration in construction', in proceedings of 17th Annual ARCOM Conference, University of Salford, 5 – 7 September 2001, pp. 929 – 938.HM Treasury (1999), 'Achieving Excellence – Constructing the Best Government Client',HM Treasury.

Halpin, D. W. and Riggs, L. S. (1992) Planning and Analysis of Construction Operations. New York.: Wiley.

Handfield, R. B. and Nichols, E. L. (1999) Introduction to Supply Chain Management. Prentice-Hall, Englewood Cliffs, NJ.

Harold R. Kerzner, 2009. Project Management: A Systems Approach to Planning, Scheduling, and Controlling. 10 Edition. Wiley.

Hatmoko, J, 2008. The impact of supply chain practice on construction project performance. Doctor of Philosophy. School of Civil Engineering and Geosciences: Newcastle University.

Holmberg, S. (1997) Measurements on an integrated supply chain. Department of Engineering Logistics, Lund University.

Houlihan, J. B. (1988) 'International supply chains: a new approach', Management decisions, 26, (3), pp. 13-19.

Impact of the influx of Syrian refugees on the Jordanian labour market : findings from the governorates of Amman, Irbid and Magraq / Svein Erik Stave and Solveig Hillesund ; International Labour Office ; Fafo Institute for Applied International Studies. - Geneva: ILO, 2015

International Organization for Standardization ISO 9000:2015[ONLINE] Available at: http://www.praxiom.com/iso-definition.htm#Supplier. [Accessed 10 September 2015].

James Taylor, 2007. Project Scheduling and Cost Control: Planning, Monitoring and Controlling the Baseline. Edition. J. Ross Publishing

Jones, T. C. and Riley, D. W. (1985) 'Using inventory for competitive advantage through supply chain management', International journal of physical distribution and materials management, 15, (5), pp. 16-26.

John W. Creswell, 2009. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 3rd Edition*. 3rd Edition. SAGE Publications, Inc.

Kadeforsi, A. (1999) ' Client-contractor relations: How fairness considerations and interest influence contractor variation negotiations, in Proceedings IGLC-7.

Kale, S. and Arditi, D. (2001) 'General contractors' relationships with subcontractors: a strategic asset', Construction Management and Economics, 19, pp. 541-549.

Khalfan, M. M. A.; Anumba, C. J.; Siemieniuch, C. E. and Sinclair, M. A. (2001), 'Readiness Assessment of the Construction Supply Chain – A Necessity for Concurrent Engineering in Construction', European Journal of Purchasing and Supply Management, Vol. 7, 2001, pp. 141 – 153.

Khalfan, M. M. A.; Anumba, C. J. & Carrillo, P. M. (2002), 'An Investigation of the Readiness of the Construction Industry for Concurrent Engineering', Construction Information Quarterly, Vol. 4, Issue 2, 2002, pp.13 – 17.

Kopczak, L. R. (1997) 'Logistics partnership and supply chain restructuring: survey results from the US computer industry', Production and Operations Management 6, (3), pp. 226-247.

Kornelius, L. and Wamelink, J. W. F. (1998) The virtual corporation: learning from construction', Supply Chain Management, 3, (4), pp. 193-202.

Koskela, L. (2003), 'Is structural change the primary solution to the problems of construction', Building Research and Information, Vol. 31, No. 2, 2003, pp. 85 – 96.

Koushki, P. A., Al-Rashid, K. and Kartam, N. (2005)'Delays and cost increases in the construction of private residential projects in Kuwait', Construction Management and Economics, 23, pp. 285-294.

Kumaraswamy, M. M. and Matthews, J. D. (2000) 'Improved subcontractor selection employing partnering principles', Journal of Management in Engineering (ASCE), 16, (3), pp. 47-57.

La Londe, B. J. and Masters, J. M. (1994) 'Emerging logistics strategies: Blueprints for the next century, International Journal of Physical Distribution & Logistics Management, 24, (7), pp. 35-47.

Lambert, D. M. and Sharman, A. (1990) 'A customer-based competitive analysis for logistics decisions', International Journal of Physical Distribution and Logistics Management 20, (1), pp. 17-24

Lambert, D. M., Stock, J. R. and Ellram, L. M. (1998) Fundamentals of logistics management. Boston: Irwin/McGraw-Hill.

Larson, E. (2007) 'Project partnering: Results of study of 280 construction project', Journal of Management in Engineering (ASCE), 11, (2), pp. 30-35.

Larson, P. D. and Halldorsson, A. (2004) 'Logistics versus supply chain management: An international survey', International Journal of Logistics, 7, (1), pp. 17-3 1.

Latham, S. M. (1994) Constructing the Team: Joint Review of Procurement and Contractual Arrangements in the United Kingdom Construction Industry. London: HMSO.

Law, A. M. and Kelton, W.D. (2000) Simulation modelling and analysis McGraw Hill.

Lee, H. L. and Billington, C. (1992) 'Managing supply chain inventory: pitfalls and opportunities', Sloan management review, 33, (3), pp. 65-73.

Lee, H. L. and Ng, S. M. (1997) 'Introduction to the special issue on global supply chain management. ' Production and Operations Management 6, (3), pp. 191-192.

Lewis, T. M. and Atherley, B. A. (1996) 'Analysis of construction delays', in Langford, D. A. and Retik, A. (eds) The organization and management of construction: shaping theory and practice. Vol. 2 London, UK: E& FN Spon, pp 404-413.

Levy, D. L. (1995) 'International sourcing and supply chain stability, Journal of International Business Studies, 26, (2), pp. 343-360.

Langford, D. A. and Retik, A. (2012) (eds) The organization and management of construction: shaping theory and practice. Vol. 2 London, UK: E& FN Spon, pp 404-413.

Law & Kelton, A .D, 2003. Simulation Modeling And Analysis. 2nd ed. London: Tata Mcgraw-Hill Publishing Company Limited, .

Maqsood, T. and Akintoye, A. (2002), ‘Supply chain management: more than a new name for management of relationships’, in proceedings of 18th Annual ARCOM Conference, Northumbria University, 2 – 4 September 2002, pp. 749 – 758.

Matthews, J., Pellew, L., Phua, F. and Rowlinson, S. (2000) 'Quality relationships: partnering in the construction supply chain', International Journal of Quality & Reliability Management, 17, (45), pp. 493-510.

Mentzer, J. T., Dewitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D. and Zacharia, Z. G. (2001) 'What is supply chain management? ' in Mentzer, J. T. (ed), Supply Chan Management. California: Sage Publications, Inc.

Meyer, Nawrocki and Walter, B, J, B, 2008. Balancing Agility and Formalism in Software Engineering. 1st ed. Germany: Springer.

Michael Haralambos, 2008. *Sociology Themes and Perspectives (Haralambos and Holborn)*. Seventh Edition, Seventh edition Edition. HarperCollins UK.

Michael R. Quayle, Bryan Jones, (2002). Logistics: An Integrated Approach. 3rd ed. England: Liverpool Business Publishing.

Muya, M. (2002) A systematic approach for improving construction materials logistics. PhD thesis. Loughborough University.

Muya, M., Price, A. D. F. and Thorpe, A. (2001)'Contractors' supplier management', in Proceeding of a Joint CIB Triennial Symposium. Cape Town:

Naim, M. M. (2003) Lesson for construction from manufacturing system engineering.

Ndekuri, I. E. (2006) Sub-contractor control, the key to successful construction. CIOB technical information service.

Neil J. Salkind, 2013. Statistics for People Who (Think They) Hate Statistics Interactive eBook Student Version. 5th ed. Edition. SAGE Publications, Inc

Nils Horch, 2009. *Management Control of Global Supply Chains*. Edition. Josef Eul Verlag GmbH.

O'Brien, C. (2002) 'Enabling Technologies for Project Supply Chain Collaboration', in NSF/ICIS Infrastructure and Information Technology Workshop. Arlington, VA, USA:

O'Brien, Formoso, Vrijhoef and London, W, C, R, K, 2009. Construction supply chain management handbook. 1st ed. United States of America : Taylor and Francis Group.

O'Brien, W. J. and Fischer, M. A. (2003) 'Construction supply-chain management: a research framework', Civil Comp 93: Information Technology for Civil and Structural Engineers, pp. 61-64.

Ochieng, Price and Moore, E, A and D, 2013. Management of global construction projects. 1st ed. London: Palgrave Macmillan.

Otto, A. and Kotzab, H. (2003) 'Does supply chain management really pay? Six perspectives to measure the performance of managing a supply chain', European Journal of Operational Research, 144, (2), pp. 306-320.

Oxford dictionaries. 2015. logistics. [ONLINE] Available at: http://www.oxforddictionaries.com/definition/english/logistics. [Accessed 13 February 16].

Oxford dictionaries. 2015. stakeholder. [ONLINE] Available at:http://www.oxforddictionaries.com/definition/english/stakeholder. [Accessed 13 January 16].

P. Gopalakrishnan, 2015. Handbook of Materials Management. 2nd Revised edition Edition. Prentice-Hall of India Pvt.Ltd.

P Weaver. 2006. Understanding PERT Programme Evaluation Review Technique. [ONLINE] Available at: http://www.mosaicprojects.com.au/WhitePapers/WP1087_PERT.pdf. [Accessed 28 August 15].

Pidd, M, 2013. Tools for thinking: modelling in management science. 3rd ed. NJ: Hoboken.

Plemmons, J. K. and Bell, L. C. (1995) 'Measuring effectiveness of materials management process', Journal of Management in Engineering (ASCE), 11, (6), pp. 26-32.

Pourrostam and Ismail, T, A, 2012. Causes and Effects of Delay in Iranian Construction Projects. *IACSIT International Journal of Engineering and Technology*, 4, 598-601.

Proverbs, D. G. and Holt, G. D. (2000) 'Reducing construction costs: European best practice supply chain implications', European Journal of Purchasing and Supply Management, 6, pp. 149-158.

Ray R. Venkataraman, 2008. Cost and Value Management in Projects. 1 Edition. Wiley.

Rushton, A., Oxley, J. and Croucher, P. (2000) The Handbook of Logistics and Distribution Management. London

Rushton, Croucher and Baker, A,P and P, 2010. The Handbook of Logistics and Distribution Management. 4th ed. London: KoganPage.

Rushton, Croucher and Baker, A,P and P, 2014. The Handbook of Logistics and Distribution Management. 5th ed. London: KoganPage.

S. Keoki Sears, 2015. Construction Project Management Sixth Edition Red Vector bundle. 6 Edition. Wiley.

Saad, M. (1996) 'Options for applying BPR in the Australian construction industry', International Journal of Project Management, 14, (6), pp. 379-385.

Sargent, R. G. (2003) 'Verification and validation of simulation models, in Chick, S., Sanchez, P. J., Ferrin, D. and Morrice, D. J. (eds), Proceedings of the 2003 Winter Simulation Conference.

Sargent, R, G, 2013. Verification and validation of simulation models. Journal of Simulation, 7, 12–24.

Schwalbe, K, 2015. *Information technology project management* . 8th ed. Boston: Cengage learning .

Scott, S., Greenwood, D. and Stitt, D. (2001) 'Improving Construction: Supply Chain Management', Construction Information Quarterly, 3, (3), pp. 1-4.

Shi, J. J. (2002) Three methods for verifying and validating the simulation of a construction operation', Construction Management and Economics, 20, pp. 483-491.

Shivers and Halper, J, J, 2012. Strategic Recreation Management. 1st ed. New York: Routledge.

Silva, F. B. D. and Cardoso, F. F. (1999) 'Applicability of logistics management in lean construction: A case study approach in Brazilian building companies', IGLC7.

Smith, G. R. and Lin, Y. -B. (1996) 'Steel framing crew performance and variation', in Langford, D. A., Retik, A. (ed), The organization and management of construction: shaping theory and practice. Vol. 2 London, UK: E& FN Spon, pp 49-59.

Stevens, G. C. (1990) 'Successful supply-chain management', Management decisions, 28, (8), pp. 25-30.

Stuckhart, G. (1995) Construction Materials Management. New York, NY: Marcel Dekker Inc.

SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION: DIAGNOSIS AND APPLICATION ISSUES | Boris Heredia Rojas - Academia.edu. 2014. *SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION: DIAGNOSIS AND APPLICATION ISSUES | Boris Heredia Rojas - Academia.edu*. [ONLINE] Available at:http://www.academia.edu/7824884/SUPPLY_CHAIN_MANAGEMENT_IN_CONSTRUCTION_DIAGNOSIS_AND_APPLICATION_ISSUES. [Accessed 13 January 2015].

Swan, W.; Cooper, R.; McDermott, P. and Wood, G. (2001), 'A review of social network analysis for the IMI trust in construction project', in proceedings of 17th Annual ARCOM Conference, University of Salford, 5 – 7 September 2001, pp. 59 – 67.

Sweis, Sweis, Abu Hammad and Shboul, G, R, A, A, 2007. Delays in construction projects: The case of Jordan. International journal of project management, 26, 665-674.

Tan, K. C. (2001) 'A framework of supply chain management literature', European Journal of Purchasing & Supply Management, 7, pp. p. 39-48.

Tan, K. C., Kannan, V. R. and Handfield, R. B. (2010) 'Supply chain management: supplier performance and firm performance', International Journal of Purchasing and Material Management, 34, (3), pp. 2-9.

Tom Kendrick. 2007. *Obtaining Useful Three-Point Estimates for Real Project Activities*. [ONLINE] Available at: http://www.failureproofprojects.com/3Point2007.pdf. [Accessed 14 January 16].

Tommelein, I. D., Riley, D. and Hershauer, J. C. (2003) Improving capital projects Supply Chain performance. A research report to the Construction Industry Institute.

Turner, J. R. (1993) 'Integrated supply chain management: what's wrong with this picture? ' Industrial engineering, 25, (12), pp. 52-55.

Venkataraman, R. (2004) 'Project supply chain management: Optimizing value: The way we manage the total supply chain', in Morris, P. W. G. and Pinto, J. K. (eds) The Wiley Guide to Managing Projects. New Jersey: John Wiley and Sons, Inc.

Vrijhoef, R. (1998) Co-makership in construction: Towards construction supply chain management. MSc Thesis thesis. Delft University of Tecnology, Delft.

Vrijhoef, R. and Koskela, L. (2000) 'The four roles of supply chain management in construction', European Journal of Purchasing & Supply Management, 6.

R. Vrijhoef, 2011. *Supply Chain Integration in the Building Industry: The Emergence of Integrated and Repetitive Strategies in a Fragmented and Project-Driven Industry*. Edition. IOS Press.

Wegelius-Lehtonen, T. (1995) 'Measuring and re-engineering logistics chains in the construction industry', in Proceedings International Federation for Information Processing working conference on re-engineering the enterprise. Galway, Ireland: University College Galway:

Wegelius-Lehtonen, T. (2001) 'Performance measurement in construction logistics', International Journal of Production Economics, 69, pp. 107-116.

Wegelius-Lehtonen, T. and Pahkala, S. (1998) 'Developing material delivery process in cooperation: An application example of the construction industry', International Journal of Production Economics, 56-57, pp. 689-69.

Will Hurst. 2013. Construction firms 'ignorant' over supply chain. [ONLINE] Available at:http://www.building.co.uk/construction-firms-ignorant-over-supply-chain/5056848.article. [Accessed 29 January 16].

Yeo, K. T. and Ning, J. H. (2002) 'Integrating supply chain and critical chain concepts in engineer-procure-construct (EPC) projects', International Journal of Project Management, 20, pp. 253-262.

Yin, R. K. (1994) Case study research: Design and methods. Beverly Hills: Sage.

Yin, R. K. (2009) Case Study Research: Design and Methods. London: Sage

Zaki, Shazwani Binti Ahmad and Mohamed, Sarajul Fikri and Yusof, Zakaria Mohd, Construction Skilled Labour Shortage – The Challenges in Malaysian Construction Sector (July 21, 2015). OIDA International Journal of Sustainable Development, Vol. 4, No. 5, pp. 99-108, 2015. Available at SSRN: http://ssrn.com/abstract=2115083

Appendices

Appendix A1: Identification of delays

According to Tindiwensi, Apolot and Alinaitwe (2013) causes of delays and cost overruns in construction projects:

1) changes in the work scope,
2) delayed payments to contractors
3) poor monitoring and control
4) high inflation
5) Interest rates.

According to Porrostam and Ismail (2012) the causes and effect of delay from consultants and contractors' viewpoint are:

1) delay in progress payment by client,
2) change orders by client during construction
3) poor site management,
4) slowness in decision making process by client,
5) financial difficulties by contractors,
6) late in reviewing and approving design documents by client,
7) Problems with subcontractors,
8) ineffective planning and scheduling of project by contractor,
9) mistakes and discrepancies in design documents
10) Bad weather.

Six major effects of delay were:

1) Time overrun,
2) Cost overrun,
3) Disputes,
4) Total abandonment,
5) Arbitration,
6) Litigation.

According to Enshassia, Kumaraswamy and Al-Najjar (2010) the most significant causes of time delay identified are:

1) Strikes and border closures
2) Lack of materials in markets
3) Shortage of construction materials at site,
4) Delay of material delivery to site
5) Cash-flow problems during construction
6) Poor site management

According to Enshassia, Kumaraswamy and Al-Najjar (2010), the causes of cost overruns are:

1) Increase in material prices due to continuous border closures
2) Delay in construction,
3) Contractors supply of raw materials and equipment
4) Fluctuations in the cost of building materials.
5) Project materials monopoly by suppliers.
6) Instability of the local currency in relation to dollar value.
7) Low commitment of donors to compensate any negative outcomes attributable to the poor economic and political situation.
8) Donor policy in awarding tenders to the lowest bidder.

According to Koushki et al (2005), identification of causes of delays and cost overruns are:

1) Orders variation
2) Financial constrains from the owners side.
3) Labour
4) Owner's lack of experience
5) Materials
6) Contractor
7) Weather

According to Frimpong and Oluwoye (2003) delays and cost overruns in construction projects are:

1) Financial factors
   - Fraudulent practice
   - Payment difficulties
   - Financial difficulties from the contractor

2) Weather factors
   - Unexpected weather conditions.
   - Environmental issues
   - Unexpected ground conditions

3) Material factors
   - Procurement problems
   - Late deliveries
   - Problems in finding material at its normal prices
   - Imported materials

4) Labour factors
   - Low skilled
   - Industrial relations
   - Management and labour relations
   - Shortage

5) Equipment/plant factors
   - Shortages
   - Breakdowns
   - Low efficiency
   - Problems in transportation

6) Project planning and controlling factor
   - Deficiencies in cost estimates, scheduling and planning prepared
   - Problems in control procedures
   - Communication
   - Insufficient management influence and authority

7) Economic factors
   - Fluctuations in the cost of equipment and materials
   - Inflation

8) External factors
   - Policies and politics
   - Restrictions
   - Inspection delays
   - Social events

9) Contract factor
   - Poor management
   - Disputes
   - Problems with insurance
   - Contract discussions
   - Unhurried decision making process

According to Al-Momani (2000) construction projects delay factors are:

1) Weather
2) Delivery delays
3) Economic conditions

4) Quantity increase
5) Poor design
6) Orders change
7) Conditions of the site.

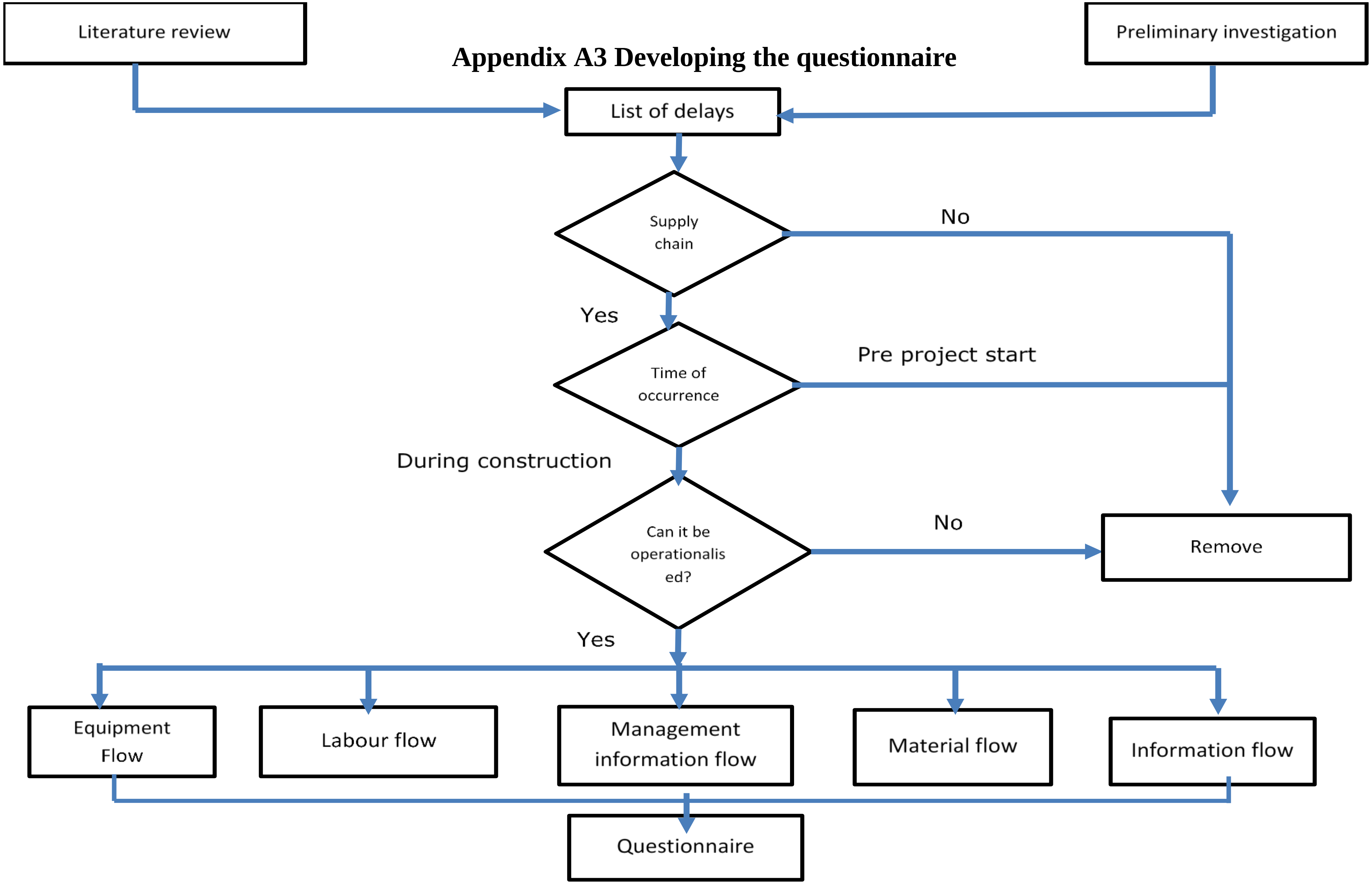
Appendix A2: Filtering supply chain delays

	Delay	Related to SCM?	Occurrence time		Impact on site activities?		Is it possible to operationalise?
Type	Specific	Is it?	Before the start	During project	Duration	Start date	Is it?
Material	Delayed delivery	Yes	-	Yes	Yes	Yes	Yes
	Low quality	Yes	-	Yes	Yes	No	Yes
	Incorrect specifications	Yes	-	Yes	Yes	Yes	Yes
	Incorrect quantity	Yes	-	Yes	Yes	Yes	Yes
	Shortage on site	Yes	-	Yes	Yes	Yes	Yes
	Problems in finding material	Yes	-	Yes	Yes	Yes	Yes
	Shortage in the market	Yes	-	Yes	Yes	Yes	Yes
	Poor planning	Yes	Yes	-	Yes	Yes	-
	Poor monitoring and control	Yes	Yes	-	Yes	Yes	-
	Damaged on arrival	Yes	-	Yes	Yes	Yes	Yes
Labour	Unskilled labour shortage	Yes	-	Yes	Yes	Yes	Yes
	Semi-skilled labour shortage	Yes	-	Yes	Yes	Yes	Yes
	High skilled labour shortage	Yes	-	Yes	Yes	Yes	Yes
	Engineers shortage	Yes	-	Yes	Yes	Yes	Yes

	Staff shortage	Yes	-	Yes	Yes	Yes	Yes
Contractor	Manpower shortage	Yes	-	Yes	Yes	Yes	Yes
	Scheduling, design and planning problems	Yes	-	Yes	Yes	Yes	-
	Problems in managing materials	Yes	-	Yes	Yes	Yes	-
	Problems in managing equipment	Yes	-	Yes	Yes	Yes	-
	unreliable subcontractors	Yes	-	Yes	Yes	Yes	-
	Subcontracted work delays	Yes	-	Yes	Yes	Yes	Yes
Client	Financial problems	-					
	Work acceptance	Yes	-	Yes	Yes	Yes	Yes
	Changing decisions	No					
Financial problems	Client						
	Contractor						
Project	Delayed information	Yes	Yes	Yes	Yes	Yes	Yes
	Cost, planning and schedule deficiencies	Yes	Yes	-	Yes	Yes	Yes
	Lack of communication between parties	Yes	Yes	Yes	Yes	Yes	Yes
	Delayed decisions	Yes	Yes	Yes	Yes	Yes	Yes

	Problems in information flow	Yes	Yes	Yes	Yes	Yes	Yes
Economic	Equipment and materials prices fluctuations	Yes	-	Yes	-	-	-
	Equipment and materials prices increase	Yes	-	Yes	-	-	Yes
Equipment	Shortage	Yes	-	Yes	Yes	Yes	Yes
	Technical problem/faults	Yes	-	Yes	Yes	Yes	-
External factors	Work approval	-	-	-	-	-	-
	Construction permit	-	-	-	-	-	-
	Weather problems	-	-	-	-	-	-
Designer	Design error	No					
	Design information delays	Yes	-	Yes	Yes	Yes	Yes
	Documents mistakes	No					
	Delayed response	Yes	-	Yes	Yes	Yes	Yes
Supplier related	Control of the market/monopoly	Yes	-	Yes	-	-	-
	Factory stoppages	Yes	-	Yes	-	-	-
	Importing difficulties	Yes	-	Yes	Yes	Yes	Yes
Governmental	Foreign currency polices related to imports	Yes	Yes	Yes	-	-	-

Appendix A3 Developing the questionnaire



Appendix A4: The questionnaire

Questionnaire

The Impact of Supply Chain Management on Construction Projects Performance in Jordan

Coventry University

Ghaith Al-Werikat

werikatg@coventry.ac.uk

Introduction

Dear participant

As part of my research on the impacts of supply chain management on construction projects performance, I would be grateful if you can take the time to complete the following questionnaire.

The aim of the questionnaire is to gather data relating to the construction supply chain in order to analyse and evaluate its impacts on construction projects performance.

The completion of the questionnaire is voluntary and all data collected regarding the participant, project and other information will be used only for the purpose of my research and will remain confidential, protected and will be destroyed after the completion of the research. Feel free to contact for any further details or information regarding the questionnaire or the research.

Thank you for your participation

Ghaith Al-Werikat

Section 1: Material flow

1- Do you receive the ordered material on time? If not, please specify the material, the potential delay in days and the probability of that occurring

material	Delay in days	percentage

2- Do you receive the exact material which you ordered? If not, please specify the material, the potential delay in days to exchange the material and the probability of that occurring

material	Delay in days	percentage

3- Does any of the material get damaged whilst on site? If so, please specify the material, the potential delay in days to exchange the material and the probability of that occurring

material	Delay in days	percentage

Section 2: Labour and equipment flow

1- Do you experience a shortage of skilled labour during the project? If so, please specify the specific skill, the potential delay it may cause to the whole project in days and the probability of that occurring

Labour	Delay in days	percentage

2- Do you experience a shortage of equipment (heavy machinery) during the project? If so, please specify the equipment, the potential delay it may cause to the whole project in days and the probability of that occurring

Equipment	Delay in days	percentage

Section three: Management and Information flow

1- Do you face any problems receiving timely accurate information regarding the projects activities from the company? If so, please specify the problem, the potential delay it may cause to the whole project in days and the probability of that occurring.

problem	Delay in days	percentage

2- Do you face any problems during the project from the client? If so, please specify the problem, the potential delay it may cause to the whole project in days and the probability of that occurring.

material	Delay in days	percentage

Appendix A5: Box plot method to detect outliers

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Material flow														
Material Delivered Later than scheduled delivery dates	**Percentage of Material Delivery Delays**	**delay on start day**			**Material Delivered with wrong specification**	**Percentage of Material Delivery Delays**	**delay on duration day**			**Material Damaged on arrival**	**Percentage of Material Delivery Delays**	**delay on start day**		
		mi	most	max			mi	most	max			mi	most	max
Concrete	10%	3	6	**9**	Concrete	19%	1	2	8	Timber	4%	2	5	8
Steel Reinforcements	7%	2	4	7	Steel Reinforcements	10%	2	5	9	Bricks	9%	1	2	3
Sand	10%	3	6	9	Bricks	7%	5	9	10	Drainage	6%	1	1.5	1.5
Bricks	8%	2	5	8	Timber	15%	4	6	8	Tools	5%	4	8	3
Scaffolding	16%	0.5	1	2	Drainage	4%	0.5	1	2	Steel	8%	4	6	12

Information flow				
Information	**percentage**	**Delay**		
		Min	Most	Max
Payment	36%	0.5	1	1
Weekly Reports	4%	1	1	2

Labour flow				
Skill shortage	percentage	Delay		
		Min	Most	Max
Electricians	9%	1	2	3
Plumbers	6%	1	1	2
Ground workers	16.4%	0.5	1	2
Surveyors	8.4%	1	3	4
Joinery	8%	1	1	5
Labourer	2.4%	1	2	3
Bricklayer	7%	1	2	3
Scaffolders	9%	4	5	7
Excavators and frame builders	8%	1	2	4
Compaction labours	11%	4	8	9
Steel workers	7.4%	3	6	7

Management information flow				
Affected activities	**percentage**	**Delay**		
		Min	Most	Max
Project documentation	24.9%	3	4	6
Objectives review	5%	0.5	1	1.5
Achievement objective	2%	0.5	1	1.5
Quality	15%	1	2	3.5
Client acceptance doc	20%	0.5	0.5	0.5
Phase review	13.5%	1	2	5

Equipment flow				
Equipment	**percentage**	**Delay**		
		Min	Most	Max
Hummer	11%	2	6	12
Crane	9%	1	4	6

Appendix A6: Main survey results

Appendix B1: Linking delays to simulation scenarios

Activity	Actual	Management	Labour	Information	Equipment	Material	All SC
Weekly status report meeting for dashboard purposes							
Weekly status report meeting for dashboard purposes 1	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 2	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 3	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 4	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 5	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 6	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 7	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 8	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 9	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting for dashboard purposes 10	1 day	1d	1d	3d	1d	1d	3d
Weekly status report meeting	1 day	1d	1d	3d	1d	1d	3d

for dashboard purposes 11							
Weekly status report meeting for dashboard purposes 12	1 day	1d	1d	3d	1d	1d	3d
Preparation							
Site offices installation	2 days	2d	5d	2d	2d	2d	5d
Project Documentation	4 days	10d	4d	4d	4d	4d	10d
Surveying	2 days	2d	6d	2d	2d	2d	6d
Equipment transportation to site	1 day	1d	1d	1d	13d	1d	13d
Preparation phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Site settlement							
Site Settlement works	3 days	3d	6d	3d	3d	3d	6d
Site settlement phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Excavation							
Excavation Work	7 days	7d	11d	7d	7d	7d	11d
Surveying work	7 days	7d	11d	7d	7d	7d	10d
Excavation phase review	1 day	6d	1d	1d	1d	1d	6d

meeting							
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Site Surveying							
Site Surveying work	1 day	1d	5d	1d	1d	1d	5d
Site Surveying phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Concrete work							
Concrete supply	1 day	1d	1d	1d	1d	10d	10d
Timber supply	1 day	1d	1d	1d	1d	9d	9d
Steel supply	1 day	1d	1d	1d	1d	13d	13d
Joinery Work	2 days	2d	7d	2d	2d	2d	7d
Casting concrete	1 day	1d	4d	1d	1d	1d	4d
Concrete work phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Formwork							
temporary	1 day	1d	5d	1d	1d	1d	5d

frame building							
Formwork phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Steel Work							
Steel Reinforcements supply	1 day	1d	1d	1d	1d	10d	10d
reinforce concrete structures	2 days	2d	6d	2d	2d	2d	5d
Steel work phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Casting concrete for Foundation							
Concrete supply	1 day	1d	1d	1d	1d	10d	10d
Casting concrete work	2 days	2d	3d	2d	2d	2d	5d
Casting concrete for foundation phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match	0.5	2d	0.5d	0.5d	0.5d	0.5d	2d

Achievement Objectives	days						
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Columns And reinforcement Works							
Steel Works	5 days	5d	12d	5d	5d	5d	12d
Joinery Works	7 days	7d	12d	7d	7d	7d	12d
Concrete supply	1 day	1d	1d	1d	1d	10d	10d
Casting concrete	1 day	1d	4d	1d	1d	1d	4d
Columns And reinforcement works phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Ground Work							
Sand supply	1 day	1d	1d	1d	1d	10d	10d
Sand Work	7 days	7d	10d	7d	7d	7d	10d
Compaction Work	13 days	13d	22d	13d	13d	13d	22d
Ground work phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Ground beams							
Joinery work	3 days	3d	8d	3d	3d	3d	8d
Steel Work	4 days	4d	11d	4d	4d	4d	11d

Casting Concrete	1 day	1d	4d	1d	1d	1d	4d
Ground beams phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Grand Work							
Sand work	1 day	1d	4d	1d	1d	1d	4d
Compaction work	2 days	2d	11d	2d	2d	2d	11d
Grand work phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Slab on grade							
Joinery work	1 day	1d	6d	1d	1d	1d	6d
Casting Concrete	2 days	2d	5d	2d	2d	2d	5d
Casting Concrete	1 day	1d	4d	1d	1d	1d	4d
Slab on grade phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5	4d	0.5d	0.5d	0.5d	0.5d	4d

	days						
Columns Work ground floor							
Steel Work	3 days	3d	10d	3d	3d	3d	10d
Joinery work	2 days	2d	7d	2d	2d	2d	7d
Concrete supply	1 day	1d	1d	1d	1d	10d	10d
Casting concrete	1 day	1d	4d	1d	1d	1d	4d
Columns work ground floor phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Slab Work							
Joinery work	2 days	2d	7d	2d	2d	2d	7d
Brick supply	1 day	1d	1d	1d	1d	11d	11d
Brick laying	1 day	1d	4d	1d	1d	1d	4d
Steel work	5 days	5d	12d	5d	5d	5d	12d
Electric work	1 day	1d	4d	1d	1d	1d	4d
Drainage supply	2 days	2d	2d	2d	2d	4d	4d
Plumbing work	1 day	1d	3d	1d	1d	1d	3d
Concrete supply	1 day	1d	1d	1d	1d	10d	10d
Casting Concrete	1 day	4d	4d	1d	1d	1d	4d
Slab work phase review meeting	1 day	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d

Bricks Work							
Bricks Laying	12 days	14d	15d	14d	14d	14d	15d
Scaffolding	2 days	4d	9d	4d	4d	4d	9d
Bricks work phase review meeting	6 days	6d	1d	1d	1d	1d	6d
Phase Objectives review	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Match Achievement Objectives	0.5 days	2d	0.5d	0.5d	0.5d	0.5d	2d
Client Acceptance	0.5 days	1d	0.5d	0.5d	0.5d	0.5d	1d
Quality	0.5 days	4d	0.5d	0.5d	0.5d	0.5d	4d
Submit Project	1 day	3d	1d	1d	1d	1d	3d

Appendix B2: Linking delays to CPM network

1	**Weekly status report meeting for dashboard purposes**	
1.1	**Weekly status report meeting for dashboard purposes 1**	*Information*
1.2	**Weekly status report meeting for dashboard purposes 2**	*Information*
1.3	**Weekly status report meeting for dashboard purposes 3**	*Information*
1.4	**Weekly status report meeting for dashboard purposes 4**	*Information*
1.5	**Weekly status report meeting for dashboard purposes 5**	*Information*
1.6	**Weekly status report meeting for dashboard purposes 6**	*Information*
1.7	**Weekly status report meeting for dashboard purposes 7**	*Information*
1.8	**Weekly status report meeting for dashboard purposes 8**	*Information*
1.9	**Weekly status report meeting for dashboard purposes 9**	*Information*
1.1o	**Weekly status report meeting for dashboard purposes 10**	*Information*
1.11	**Weekly status report meeting for dashboard purposes 11**	*Information*
1.12	**Weekly status report meeting for dashboard purposes 12**	*Information*
2	**Preparation**	
2.1	**Site offices installation**	*Labour*
2.2	**Project Documentation**	*Management*
2.3	**Surveying**	*Labour*
2.4	**Equipment transportation to site**	*Equipment*
2.5	**Preparation phase review meeting**	
2.5.1	Phase Objectives review	*Management*
2.5.2	Match Achievement Objectives	*Management*
2.5.3	Client Acceptance	*Management*
2.5.4	Quality	*Management*
3	**Site settlement**	
3.1	**Site Settlement works**	*Labour*
3.2	**Site settlement phase review meeting**	
3.2.1	Phase Objectives review	*Management*
3.2.2	Match Achievement Objectives	*Management*
3.2.3	Client Acceptance	*Management*
3.2.4	Quality	*Management*
4	**Excavation**	
4.1	**Excavation Work**	*Labour*
4.2	**Surveying work**	*Labour*
4.3	**Excavation phase review meeting**	
4.3.1	Phase Objectives review	*Management*
4.3.2	Match Achievement Objectives	*Management*
4.3.3	Client Acceptance	*Management*
4.3.4	Quality	*Management*
5	**Site Surveying**	
5.1	**Site Surveying work**	*Labour*
5.2	**Site Surveying phase review meeting**	
5.2.1	Phase Objectives review	*Management*

5.2.2	Match Achievement Objectives	*Management*
5.2.3	Client Acceptance	*Management*
5.2.4	Quality	*Management*
6	**Concrete work**	
6.1	**Concrete supply**	*Material*
6.2	**Timber supply**	*Material*
6.3	**Steel supply**	*Material*
6.4	**Joinery Work**	*Labour*
6.5	**Casting concrete**	*Labour*
6.6	**Concrete work phase review meeting**	
6.6.1	Phase Objectives review	*Management*
6.6.2	Match Achievement Objectives	*Management*
6.6.3	Client Acceptance	*Management*
6.6.4	Quality	*Management*
7	**Formwork**	
7.1	**temporary frame building**	*Labour*
7.2	**Formwork phase review meeting**	
7.2.1	Phase Objectives review	*Management*
7.2.2	Match Achievement Objectives	*Management*
7.2.3	Client Acceptance	*Management*
7.2.4	Quality	*Management*
8	**Steel Work**	
8.1	**Steel Reinforcements supply**	*Material*
8.2	**reinforce concrete structures**	*Labour*
8.3	**Steel work phase review meeting**	
8.3.1	Phase Objectives review	*Management*
8.3.2	Match Achievement Objectives	*Management*
8.3.3	Client Acceptance	*Management*
8.3.4	Quality	*Management*
9	**Casting concrete for Foundation**	
9.1	**Concrete supply**	*Material*
9.2	**Casting concrete work**	*Labour*
9.3	**Casting concrete for foundation phase review meeting**	
9.3.1	Phase Objectives review	*Management*
9.3.2	Match Achievement Objectives	*Management*
9.3.3	Client Acceptance	*Management*
9.3.4	Quality	*Management*
10	**Columns And reinforcement Works**	
10.1	**Steel Works**	*Labour*
10.2	**Joinery Works**	*Labour*
10.3	**Concrete supply**	*Material*
10.4	**Casting concrete**	*Labour*
10.5	**Columns And reinforcement works phase review meeting**	

10.5.1	Phase Objectives review	*Management*
10.5.2	Match Achievement Objectives	*Management*
10.5.3	Client Acceptance	*Management*
10.5.4	Quality	*Management*
11	**Groundwork**	
11.1	**Sand supply**	*Material*
11.2	**Sand Work**	*Labour*
11.3	**Compaction Work**	*Labour*
11.4	**Groundwork phase review meeting**	
11.4.1	Phase Objectives review	*Management*
11.4.2	Match Achievement Objectives	*Management*
11.4.3	Client Acceptance	*Management*
11.4.4	Quality	*Management*
12	**Ground beams**	
12.1	**Joinery work**	*Labour*
12.2	**Steel Work**	*Labour*
12.3	**Casting Concrete**	*Labour*
12.4	**Ground beams phase review meeting**	
12.4.1	Phase Objectives review	*Management*
12.4.2	Match Achievement Objectives	*Management*
12.4.3	Client Acceptance	*Management*
12.4.4	Quality	*Management*
13	**Groundwork**	
13.1	**Sand work**	*Labour*
13.2	**Compaction work**	*Labour*
13.3	**Groundwork phase review meeting**	
13.3.1	Phase Objectives review	*Management*
13.3.2	Match Achievement Objectives	*Management*
13.3.3	Client Acceptance	*Management*
13.3.4	Quality	*Management*
14	**Slab on grade**	
14.1	**Joinery work**	*Labour*
14.2	**Casting Concrete**	*Labour*
14.3	**Casting Concrete**	*Labour*
14.4	**Slab on grade phase review meeting**	
14.4.1	Phase Objectives review	*Management*
14.4.2	Match Achievement Objectives	*Management*
14.4.3	Client Acceptance	*Management*
14.4.4	Quality	*Management*
15	**Columns Work ground floor**	
15.1	**Steel Work**	*Labour*
15.2	**Joinery work**	*Labour*
15.3	**Concrete supply**	*Material*

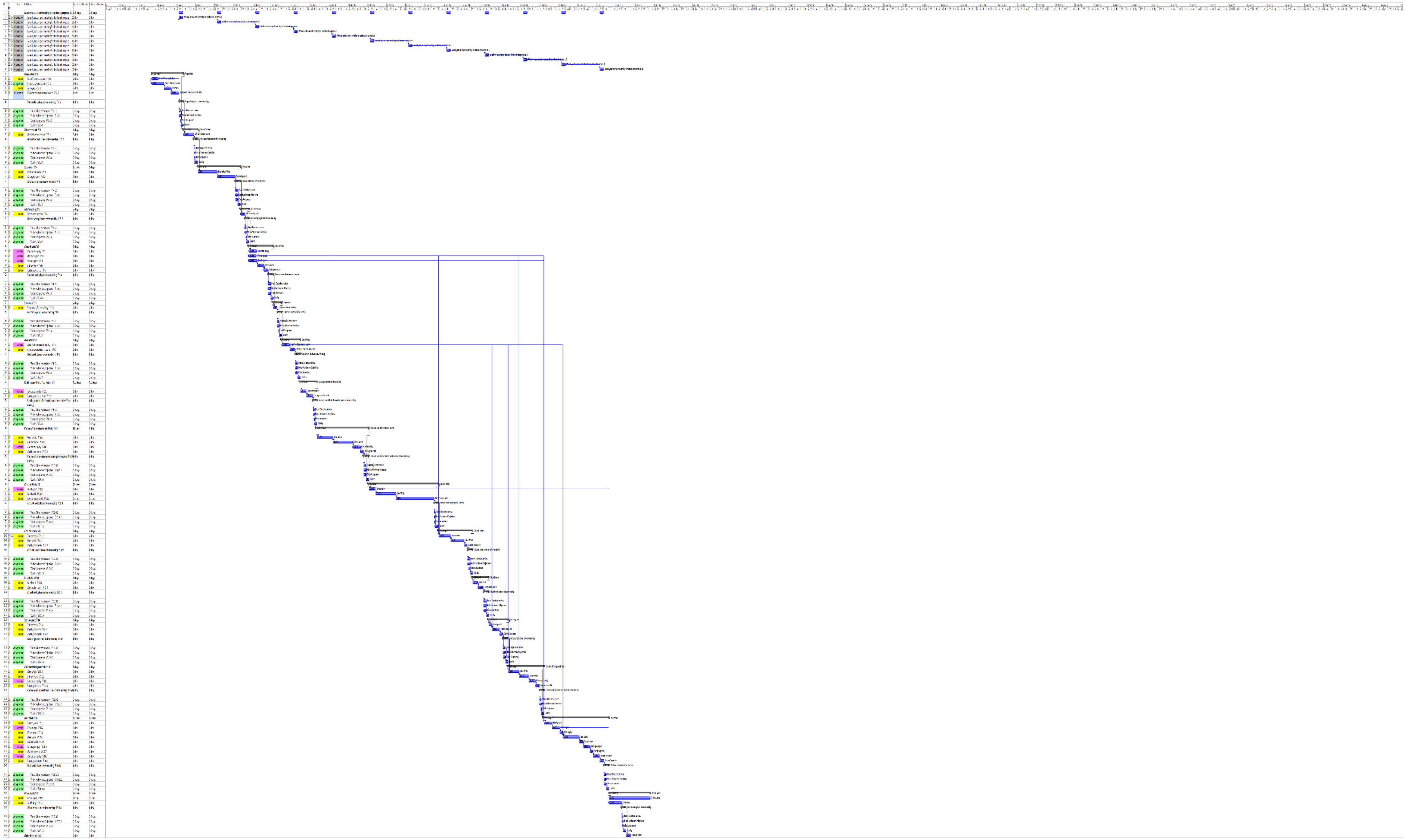
15.4	**Casting concrete**	*Labour*
15.5	**Columns work ground floor phase review meeting**	
15.5.1	Phase Objectives review	*Management*
15.5.2	Match Achievement Objectives	*Management*
15.5.3	Client Acceptance	*Management*
15.5.4	Quality	*Management*
16	**Slab Work**	
16.1	**Joinery work**	*Labour*
16.2	**Brick supply**	*Material*
16.3	**Brick laying**	*Labour*
16.4	**Steel work**	*Labour*
16.5	**Electric work**	*Labour*
16.6	**Drainage supply**	*Material*
16.7	**Plumbing work**	*Labour*
16.8	**Concrete supply**	*Material*
16.9	**Casting Concrete**	*Labour*
16.1	**Slab work phase review meeting**	
16.10.1	Phase Objectives review	*Management*
16.10.2	Match Achievement Objectives	*Management*
16.10.3	Client Acceptance	*Management*
16.10.4	Quality	*Management*
17	**Bricks Work**	
17.1	**Bricks Laying**	*Labour*
17.2	**Scaffolding**	*Labour*
17.3	**Bricks work phase review meeting**	
17.3.1	Phase Objectives review	*Management*
17.3.2	Match Achievement Objectives	*Management*
17.3.3	Client Acceptance	*Management*
17.3.4	Quality	*Management*
18	**Submit Project**	

Appendix B3: Resources in the CPM network

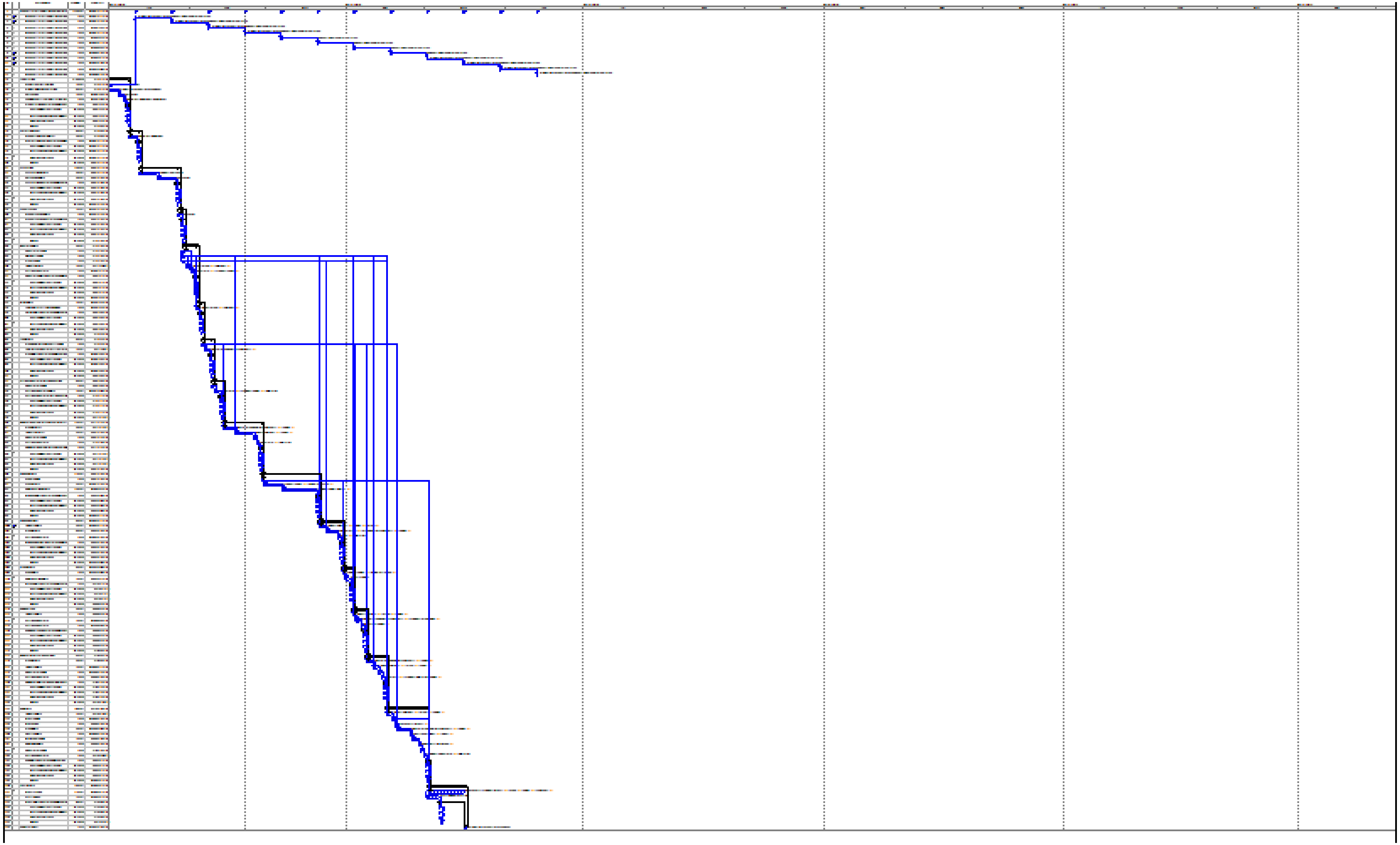
Resource Name	Resource Type
Hummer	Cost
Bulldozer	Cost
Dumper	Cost
Scaffolding	Cost
Vibratory	Cost
Roller	Cost
Scaffolding	Cost
Joiner	Work
Project Manager	Work
Site Engineer	Work
Scaffolder	Work
Smith	Work
Bricklayers	Work
Electrician	Work
Plumbers	Work
Plasterer	Work
Labour	Work
Surveyor	Work
Sand	Material
Steel Tools	Material
Concrete	Material
water	Material
Plugs	Material
cement	Material
Steel Reinforcements	Material
Pipes	Material
Bricks	Material
Windows & Doors	Material
Timber	Material
Steel	Material
Tools	Material
Drainage	Material
Client Representative	Work

Appendix C1: All Supply chain delays CPM

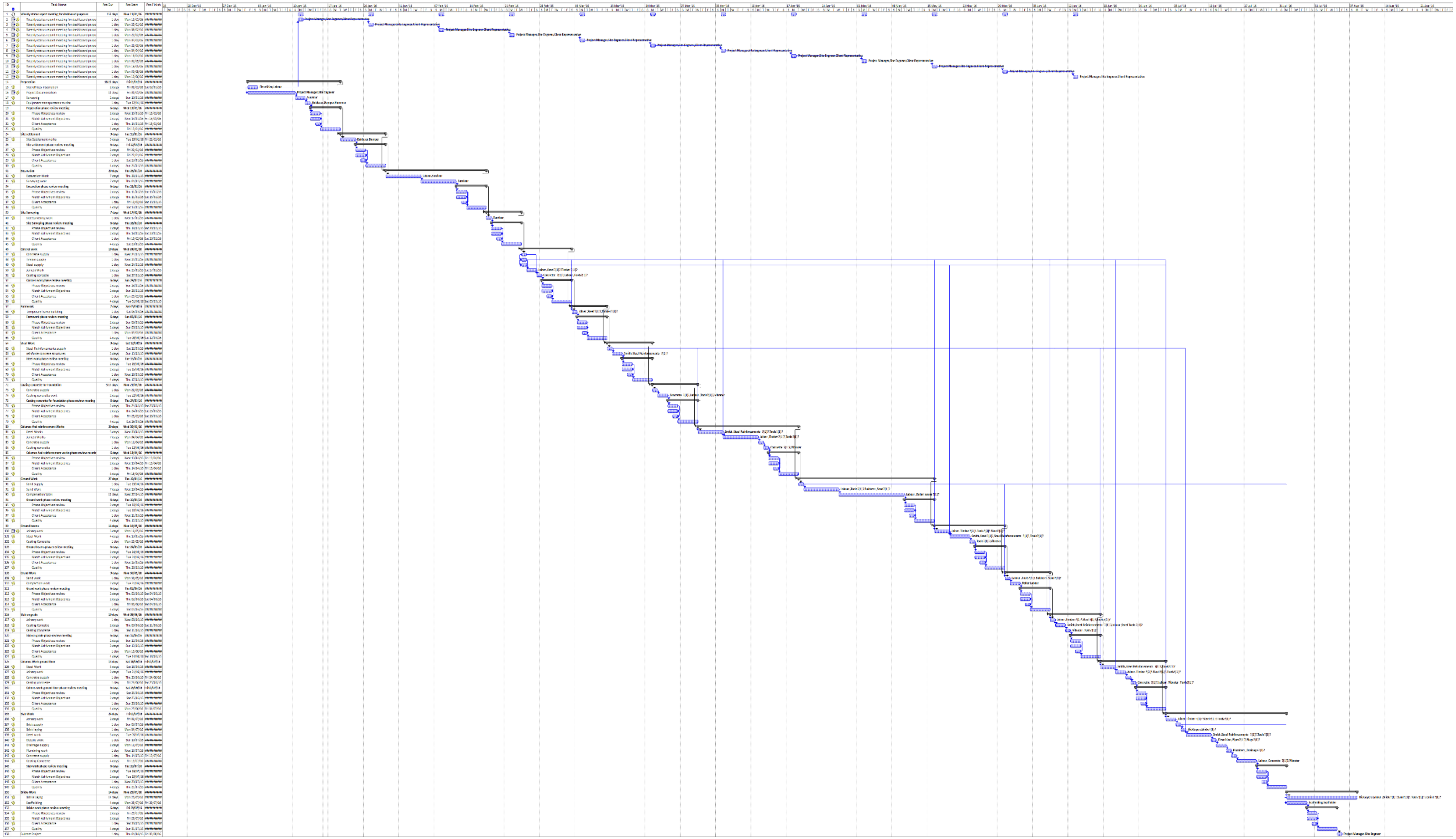
Appendix C2: Initial CPM



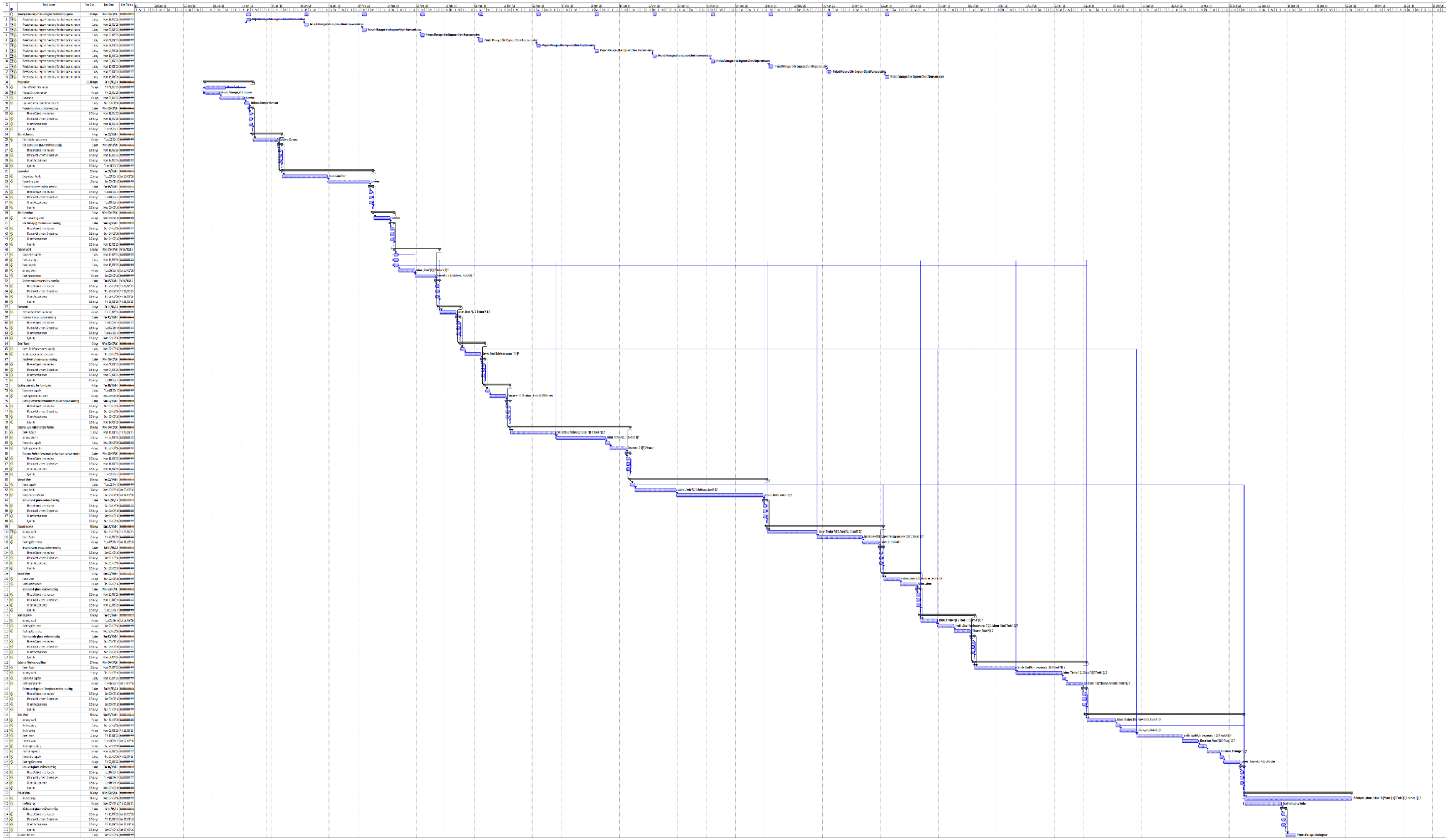
Appendix C3: Actual CPM



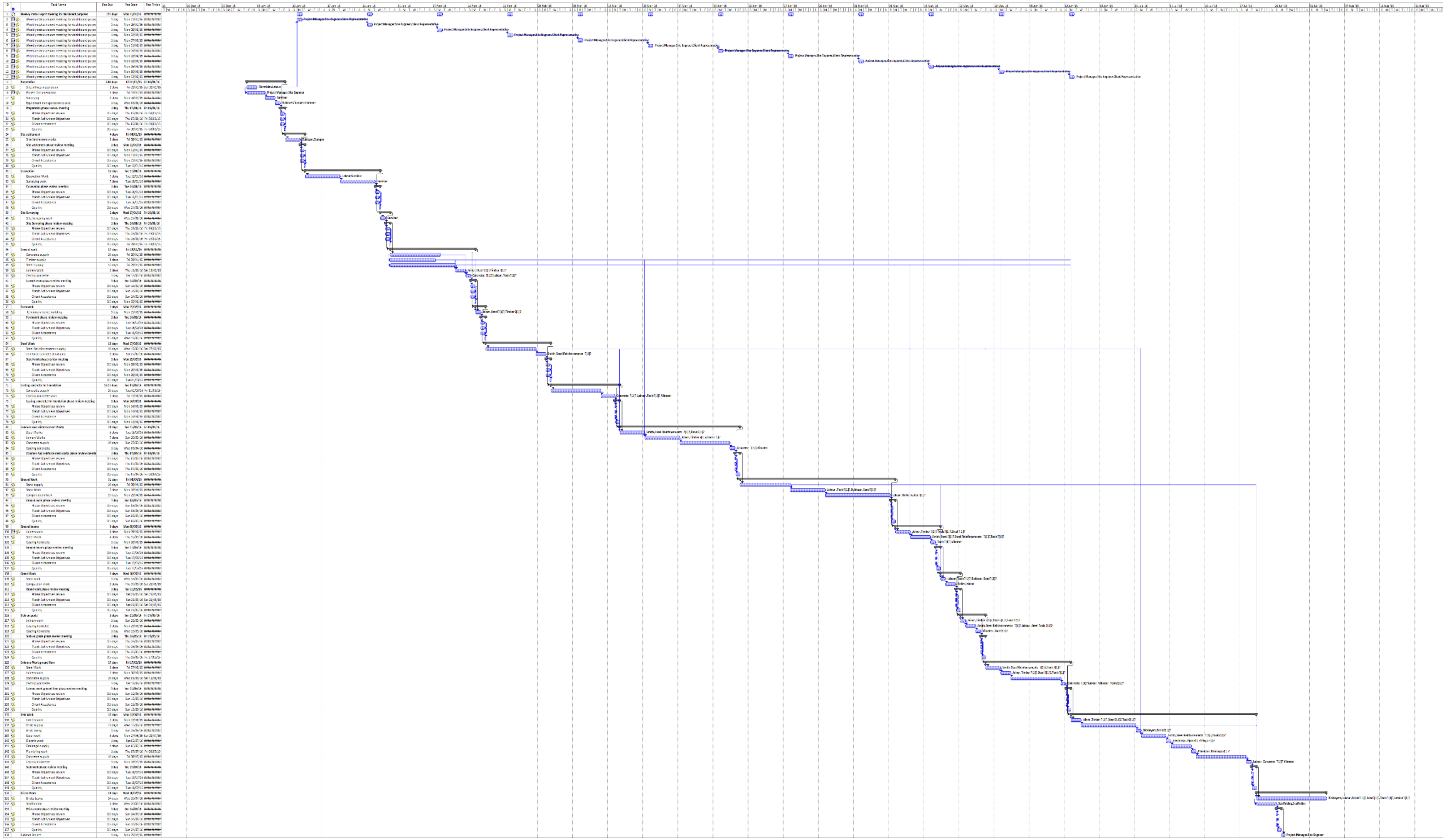
Appendix C4: Management information delays



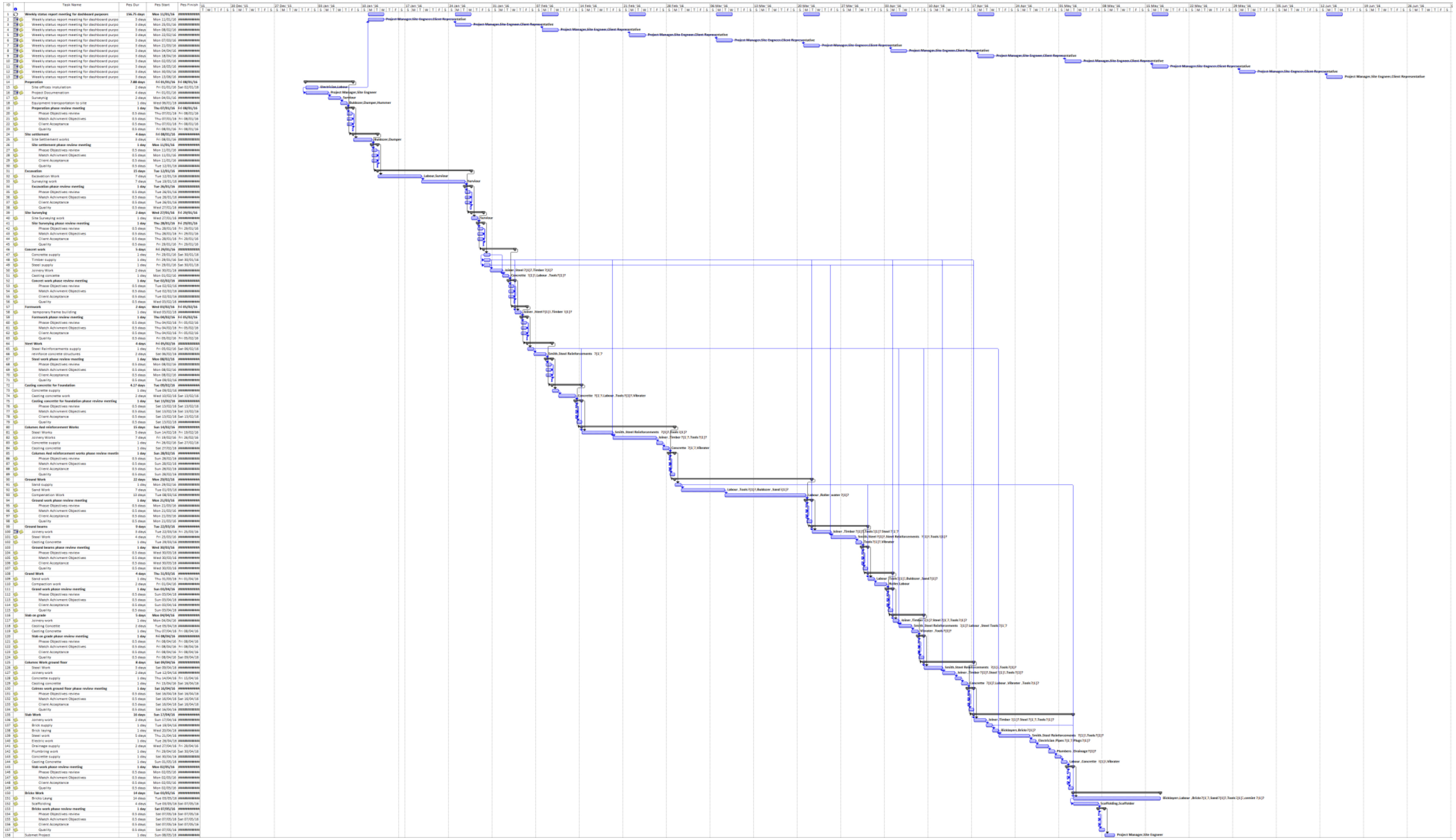
Appendix C5: Labour flow delays



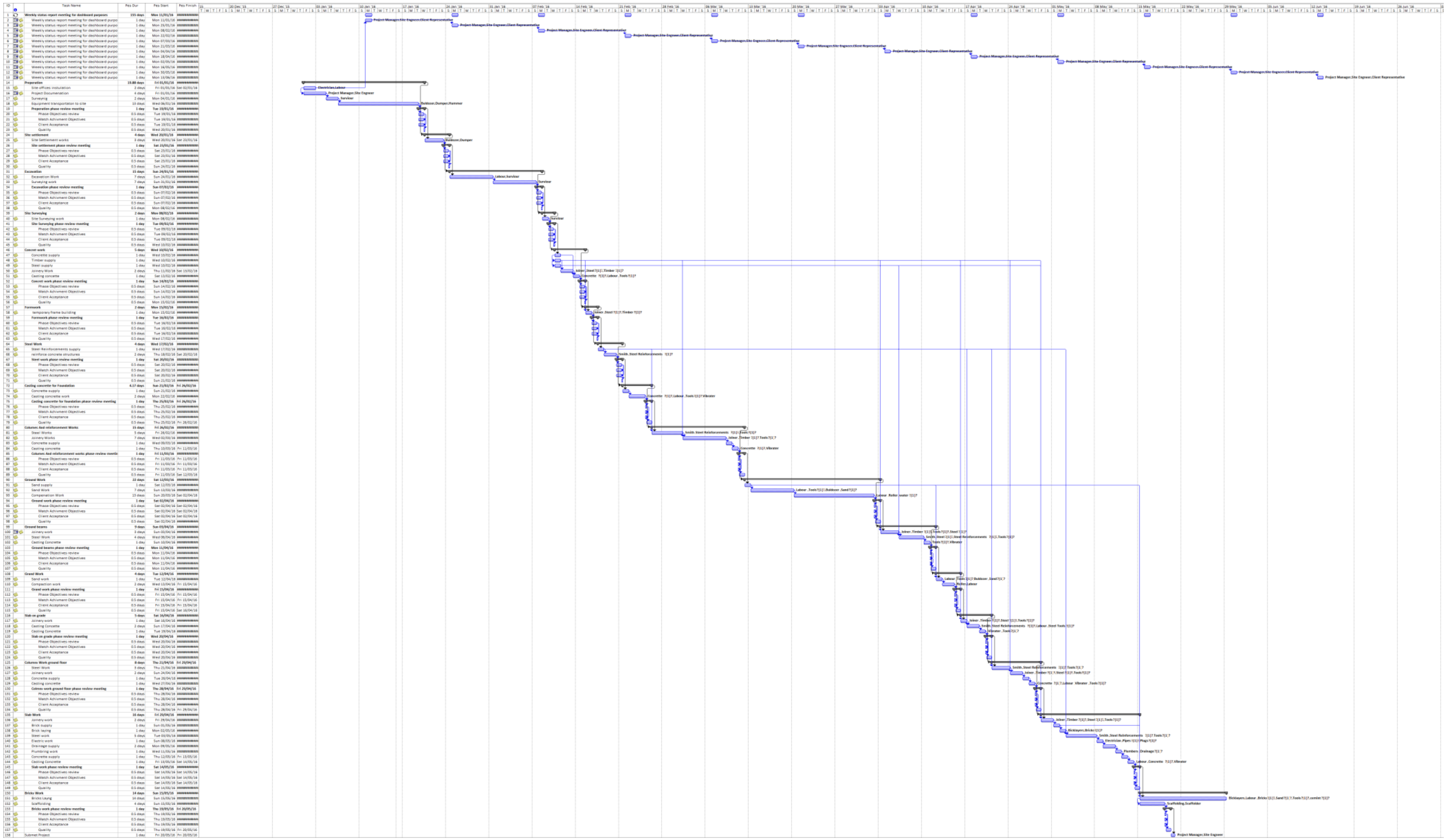
Appendix C6: Material flow delays



Appendix C7: Information flow delays



Appendix C8: Equipment flow delays



Appendix D1: Trace validation matrix

Activity	Actual	All SC	Delay	Management	Delay	Labour	Delay	Material	Delay	Info	Delay	Equip	Delay
Weekly status report meeting													
Weekly status report meeting 1	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 2	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 3	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 4	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 5	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 6	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 7	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 8	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 9	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 10	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 11	1	3	2	1	0	1	0	1	0	3	2	1	0
Weekly status report meeting 12	1	3	2	1	0	1	0	1	0	3	2	1	0
Preparation							4		0		0		
Site offices installation	2	5	3	2	0	5	3	2	0	2	0	2	0
Project Documentation	4	10	6	10	6	4	0	4	0	4	0	4	0
Surveying	2	6	4	2	0	6	4	2	0	2	0	2	0
Equipment transportation to site	1	13	12	1	0	1	0	1	0	1	0	13	12

Preparation phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Site settlement									0		0		
Site Settlement works	3	6	3	3	0	6	3	3	0	3	0	3	0
Site settlement phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Excavation													
Excavation Work	7	11	4	7	0	11	4	7	0	7	0	7	0
Surveying work	7	11	4	7	0	11	4	7	0	7	0	7	0
Excavation phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Site Surveying													
Site Surveying work	1	5	4	1	0	5	4	1	0	1	0	1	0
Site Surveying phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0

Concrete work													
Concrete supply	1	10	9	1	0	1	0	10	9	1	0	1	0
Timber supply	1	9	8	1	0	1	0	9	8	1	0	1	0
Steel supply	1	13	12	1	0	1	0	13	12	1	0	1	0
Joinery Work	2	7	5	2	0	7	5	2	0	2	0	2	0
Casting concrete	1	4	3	1	0	4	3	1	0	1	0	1	0
Concrete work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Formwork													
temporary frame building	1	5	4	1	0	5	4	1	0	1	0	1	0
Formwork phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Steel Work													
Steel Reinforcements supply	1	10	9	1	0	1	0	10	9	1	0	1	0
reinforce concrete structures	2	5	3	2	0	6	4	2	0	2	0	2	0
Steel work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Casting concrete for Foundation													
Concrete supply	1	10	9	1	0	1	0	10	9	1	0	1	0

Casting concrete work	2	5	3	2	0	3	1	2	0	2	0	2	0
Casting concrete for foundation phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Columns And reinforcement Works													
Steel Works	5	12	7	5	0	12	7	5	0	5	0	5	0
Joinery Works	7	12	5	7	0	12	5	7	0	7	0	7	0
Concrete supply	1	10	9	1	0	1	0	10	9	1	0	1	0
Casting concrete	1	4	3	1	0	4	3	1	0	1	0	1	0
Columns And reinforcement works phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Ground Work													
Sand supply	1	10	9	1	0	1	0	10	9	1	0	1	0
Sand Work	7	10	3	7	0	10	3	7	0	7	0	7	0
Compaction Work													
Ground work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Ground beams													
Joinery work	3	8	5	3	0	8	5	3	0	3	0	3	0

Steel Work	4	11	7	4	0	11	7	4	0	4	0	4	0
Casting Concrete	1	4	3	1	0	4	3	1	0	1	0	1	0
Ground beams phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Grand Work													
Sand work	1	4	3	1	0	4	3	1	0	1	0	1	0
Compaction work	2	11	9	2	0	11	9	2	0	2	0	2	0
Grand work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Slab on grade													
Joinery work	1	6	5	1	0	6	5	1	0	1	0	1	0
Casting Concrete	2	5	3	2	0	5	3	2	0	2	0	2	0
Casting Concrete	1	4	3	1	0	4	3	1	0	1	0	1	0
Slab on grade phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Columns Work ground floor													
Steel Work	3	10	7	3	0	10	7	3	0	3	0	3	0
Joinery work	2	7	5	2	0	7	5	2	0	2	0	2	0
Concrete supply	1	10	9	1	0	1	0	10	9	1	0	1	0
Casting concrete	1	4	3	1	0	4	3	1	0	1	0	1	0

Columns work ground floor phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Slab Work													
Joinery work	2	7	5	2	0	7	5	2	0	2	0	2	0
Brick supply	1	11	10	1	0	1	0	11	10	1	0	1	0
Brick laying	1	4	3	1	0	4	3	1	0	1	0	1	0
Steel work	5	12	7	5	0	12	7	5	0	5	0	5	0
Electric work	1	4	3	1	0	4	3	1	0	1	0	1	0
Drainage supply	2	4	2	2	0	2	0	4	2	2	0	2	0
Plumbing work	1	3	2	1	0	3	2	1	0	1	0	1	0
Concrete supply	1	10	9	1	0	1	0	10	9	1	0	1	0
Casting Concrete	1	4	3	4	3	4	3	1	0	1	0	1	0
Slab work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Bricks Work	14	26	12	26	12	26	12	14	0	14	0	14	0
Bricks Laying	12	15	3	14	2	15	3	14	2	14	2	14	2
Scaffolding	2	9	7	4	2	9	7	4	2	4	2	4	2
Bricks work phase review meeting	1	6	5	6	5	1	0	1	0	1	0	1	0
Phase Objectives review	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Match Achievement Objectives	0.5	2	1.5	2	1.5	0.5	0	0.5	0	0.5	0	0.5	0
Client Acceptance	0.5	1	0.5	1	0.5	0.5	0	0.5	0	0.5	0	0.5	0
Quality	0.5	4	3.5	4	3.5	0.5	0	0.5	0	0.5	0	0.5	0
Submit Project													

Appendix E1: Trace validation for all supply chain flow delays

Type	Activity	Resource	Value	All SC	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	3	1	2
I	Weekly status report meeting 2	Client	2	3	1	2
I	Weekly status report meeting 3	Client	2	3	1	2
I	Weekly status report meeting 4	Client	2	3	1	2
I	Weekly status report meeting 5	Client	2	3	1	2
I	Weekly status report meeting 6	Client	2	3	1	2
I	Weekly status report meeting 7	Client	2	3	1	2
I	Weekly status report meeting 8	Client	2	3	1	2
I	Weekly status report meeting 9	Client	2	3	1	2
I	Weekly status report meeting 10	Client	2	3	1	2
I	Weekly status report meeting 11	Client	2	3	1	2
I	Weekly status report meeting 12	Client	2	3	1	2
	Preparation					
L	Site offices installation	Labourer	3	5	2	3
MI	Project Documentation	Documentation	6	10	4	6
L	Surveying	Labourer	4	6	2	4
E	Equipment transportation to site	Equipment	12	13	1	12
MI	Preparation phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Site settlement					
L	Site Settlement works	Labourer	3	6	3	3
	Site settlement phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Excavation					
L	Excavation Work	Ground workers	4	11	7	4
L	Surveying work	Surveyor	3	10	7	3
MI	Excavation phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Site Surveying					
L	Site Surveying work	Surveyors	4	5	1	4
MI	Site Surveying phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Concert work					
M	Concrete supply	Concrete	9	10	1	9
M	Timber supply	Timber	8	9	1	8
M	Steel supply	Steel	12	13	1	12
L	Joinery Work	Joiner	5	7	2	5

L	Casting concrete	Labourer	3	4	1	3
MI	Concert work phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Formwork					
L	temporary frame building	Semi-skilled	4	5	1	4
MI	Formwork phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
L	Steel Work					
M	Steel Reinforcements supply	Steel reinforcement	9	10	1	9
L	reinforce concrete structures	Labourer	3	5	2	3
MI	Steel work phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Casting concrete for Foundation					
M	Concrete supply	Concrete	9	10	1	9
L	Casting concrete work	Labourer	3	5	2	3
MI	Casting concrete for foundation phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	12	5	7
L	Joinery Works		5	12	7	5
M	Concrete supply		9	10	1	9
L	Casting concrete		3	4	1	3
MI	Columns And reinforcement works phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Ground Work					
M	Sand supply	Sand	9	10	1	9
L	Sand Work	Sand	3	10	7	3
	Compaction Work					
MI	Ground work phase review meeting		5	6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Ground beams					

L	Joinery work	Joinery	5	8	3	5
L	Steel Work	Steel workers	7	11	4	7
L	Casting Concrete	Labour	3	4	1	3
MI	Ground beams phase review meeting		5	6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Ground Work					
L	Sand work	Labourer	3	4	1	3
L	Compaction work	Other skilled	9	11	2	9
MI	Grand work phase review meeting		5	6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Slab on grade					
L	Joinery work	Joiner	5	6	1	5
L	Casting Concrete	Labourer	3	5	2	3
L	Casting Concrete	Labourer	3	4	1	3
MI	Slab on grade phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Columns Work ground floor					
L	Steel Work	Steel workers	7	10	3	7
L	Joinery work	Joinery	5	7	2	5
M	Concrete supply	Concrete	9	10	1	9
L	Casting concrete	Labourer	3	4	1	3
MI	Columns work ground floor phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Slab Work					
L	Joinery work	Joiner	5	7	2	5
M	Brick supply	Bricks	10	11	1	10
L	Brick laying	Bricklayer	3	4	1	3
L	Steel work	Steel workers	7	12	5	7
L	Electric work	Electrician	3	4	1	3
M	Drainage supply	Drainage	2	4	2	2
L	Plumbing work	Plumber	2	3	1	2
M	Concrete supply	Concrete	9	10	1	9
L	Casting Concrete	Labourer	3	4	1	3
MI	Slab work phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
L	Bricks Work					
L	Bricks Laying	Bricklayer	3	15	12	3

L	Scaffolding	Scaffolder	7	9	2	7
MI	Bricks work phase review meeting			6	1	5
MI	Phase Objectives review	Phase Rev	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Achiev. Obj	1.5	2	0.5	1.5
MI	Client Acceptance	Client Acc.	0.5	1	0.5	0.5
MI	Quality	Quality	3.5	4	0.5	3.5
	Submit Project	Management		3	1	2

Appendix E2: Trace validation for management information delays flow

Type	Activity	Resource	Value	Management	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	1	1	0
I	Weekly status report meeting 2	Client	2	1	1	0
I	Weekly status report meeting 3	Client	2	1	1	0
I	Weekly status report meeting 4	Client	2	1	1	0
I	Weekly status report meeting 5	Client	2	1	1	0
I	Weekly status report meeting 6	Client	2	1	1	0
I	Weekly status report meeting 7	Client	2	1	1	0
I	Weekly status report meeting 8	Client	2	1	1	0
I	Weekly status report meeting 9	Client	2	1	1	0
I	Weekly status report meeting 10	Client	2	1	1	0
I	Weekly status report meeting 11	Client	2	1	1	0
I	Weekly status report meeting 12	Client	2	1	1	0
	Preparation					
L	Site offices installation	Labourer	3	2	2	0
MI	Project Documentation	Management	6	10	4	6
L	Surveying	Labourer	4	2	2	0
E	Equipment transportation to site	Equipment	12	1	1	0
MI	Preparation phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Site settlement					
L	Site Settlement works	Labourer	3	3	3	0
	Site settlement phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Excavation					
L	Excavation Work	Ground workers	4	7	7	0
L	Surveying work	Surveyor	3	7	7	0
	Excavation phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Site Surveying					
L	Site Surveying work	Surveyors	4	1	1	0
	Site Surveying phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5

	Concert work					
M	Concrete supply	Concrete	9	1	1	0
M	Timber supply	Timber	8	1	1	0
M	Steel supply	Steel	12	1	1	0
L	Joinery Work	Joiner	5	2	2	0
L	Casting concrete	Labourer	3	1	1	0
	Concert work phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Formwork					
L	temporary frame building	Semi-skilled	4	1	1	0
	Formwork phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
L	Steel Work					
M	Steel Reinforcements supply	Steel reinforcement	9	1	1	0
L	reinforce concrete structures	Labourer	3	2	2	0
	Steel work phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Casting concrete for Foundation			20	4	16
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete work	Labourer	3	2	2	0
	Casting concrete for foundation phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	5	5	0
L	Joinery Works		5	7	7	0
M	Concrete supply		9	1	1	0
L	Casting concrete		3	1	1	0
	Columns And reinforcement works phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Ground Work			47	22	25
M	Sand supply	Sand	9	1	1	0
L	Sand Work	Sand	3	7	7	0
L	Compaction Work			13	13	0
MI	Ground work phase review meeting		5	6	1	5

MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Ground beams					
L	Joinery work	Joinery	5	3	3	0
L	Steel Work	Steel workers	7	4	4	0
L	Casting Concrete	Labour	3	1	1	0
MI	Ground beams phase review meeting		5	6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Ground Work			14	4	10
L	Sand work	Labourer	3	1	1	0
L	Compaction work	Other skilled	9	2	2	0
	Grand work phase review meeting		5	6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Slab on grade			18	5	13
L	Joinery work	Joiner	5	1	1	0
L	Casting Concrete	Labourer	3	2	2	0
L	Casting Concrete	Labourer	3	1	1	0
	Slab on grade phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Columns Work ground floor					
L	Steel Work	Steel workers	7	3	3	0
L	Joinery work	Joinery	5	2	2	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete	Labourer	3	1	1	0
	Columns work ground floor phase review meeting			6	1	5
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Slab Work					
L	Joinery work	Joiner	5	2	2	0
M	Brick supply	Bricks	10	1	1	0
L	Brick laying	Bricklayer	3	1	1	0
L	Steel work	Steel workers	7	5	5	0
L	Electric work	Electrician	3	1	1	0
M	Drainage supply	Drainage	2	2	2	0
L	Plumbing work	Plumber	2	1	1	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting Concrete	Labourer	3	4	1	0
	Slab work phase review meeting			6	1	5

MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
	Bricks Work					
L	Bricks Laying	Bricklayer	3	14	12	2
L	Scaffolding	Scaffolder	7	4	2	2
	Bricks work phase review meeting			6	1	0
MI	Phase Objectives review	Management	1.5	2	0.5	1.5
MI	Match Achievement Objectives	Management	1.5	2	0.5	1.5
MI	Client Acceptance	Management	0.5	1	0.5	0.5
MI	Quality	Management	3.5	4	0.5	3.5
MI	Submit Project	Management		1	1	0

Appendix E3: Trace validation for labour flow delays

Type	Activity	Resource	Value	Labour	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	**1**	1	0
I	Weekly status report meeting 2	Client	2	**1**	1	**0**
I	Weekly status report meeting 3	Client	2	**1**	1	0
I	Weekly status report meeting 4	Client	2	**1**	1	**0**
I	Weekly status report meeting 5	Client	2	**1**	1	0
I	Weekly status report meeting 6	Client	2	**1**	1	**0**
I	Weekly status report meeting 7	Client	2	**1**	1	0
I	Weekly status report meeting 8	Client	2	**1**	1	**0**
I	Weekly status report meeting 9	Client	2	**1**	1	0
I	Weekly status report meeting 10	Client	2	**1**	1	**0**
I	Weekly status report meeting 11	Client	2	**1**	1	0
I	Weekly status report meeting 12	Client	2	**1**	1	**0**
	Preparation					
L	Site offices installation	Labourer	3	**5**	2	**3**
MI	Project Documentation	Management	6	**4**	4	0
L	Surveying	Labourer	4	**6**	2	**4**
E	Equipment transportation to site	Equipment	12	**1**	1	0
MI	Preparation phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Site settlement					
L	Site Settlement works	Labourer	3	**6**	3	**3**
MI	Site settlement phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Excavation					
L	Excavation Work	Ground workers	4	**11**	7	4
L	Surveying work	Surveyor	3	**11**	7	**4**
MI	Excavation phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Site Surveying					
L	Site Surveying work	Surveyors	4	**5**	1	4
MI	Site Surveying phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Concert work					
M	Concrete supply	Concrete	9	**1**	1	**0**

M	Timber supply	Timber	8	**1**	1	0
M	Steel supply	Steel	12	**1**	1	**0**
L	Joinery Work	Joiner	5	**7**	2	5
L	Casting concrete	Labourer	3	**4**	1	**3**
MI	Concert work phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Formwork					
L	temporary frame building	Semi-skilled	4	**5**	1	4
MI	Formwork phase review meeting					
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
L	Steel Work		16	**6**	4	2
M	Steel Reinforcements supply	Steel reinforcement	9	**1**	1	**0**
L	reinforce concrete structures	Labourer	3	**6**	2	4
MI	Steel work phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Casting concrete for Foundation					
M	Concrete supply	Concrete	9	**1**	1	**0**
L	Casting concrete work	Labourer	3	**3**	2	1
MI	Casting concrete for foundation phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	**12**	5	**7**
L	Joinery Works		5	**12**	7	5
M	Concrete supply		9	**1**	1	**0**
L	Casting concrete		3	**4**	1	3
MI	Columns And reinforcement works phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Ground Work					
M	Sand supply	Sand	9	**1**	1	**0**
L	Sand Work	Sand	3	**10**	7	3
	Compaction Work					
MI	Ground work phase review meeting		5	**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0

MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Ground beams					
L	Joinery work	Joinery	5	**8**	3	5
L	Steel Work	Steel workers	7	**11**	4	**7**
L	Casting Concrete	Labour	3	**4**	1	3
MI	Ground beams phase review meeting		5	**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Ground Work					
L	Sand work	Labourer	3	**4**	1	**3**
L	Compaction work	Other skilled	9	**11**	2	9
MI	Grand work phase review meeting		5	**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Slab on grade					
L	Joinery work	Joiner	5	**6**	1	**5**
L	Casting Concrete	Labourer	3	**5**	2	3
L	Casting Concrete	Labourer	3	**4**	1	**3**
MI	Slab on grade phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Columns Work ground floor					
L	Steel Work	Steel workers	7	**10**	3	7
L	Joinery work	Joinery	5	**7**	2	**5**
M	Concrete supply	Concrete	9	**1**	1	0
L	Casting concrete	Labourer	3	**4**	1	**3**
MI	Columns work ground floor phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Slab Work					
L	Joinery work	Joiner	5	**7**	2	5
M	Brick supply	Bricks	10	**1**	1	**0**
L	Brick laying	Bricklayer	3	**4**	1	3
L	Steel work	Steel workers	7	**12**	5	**7**
L	Electric work	Electrician	3	**4**	1	3
M	Drainage supply	Drainage	2	**2**	2	**0**
L	Plumbing work	Plumber	2	**3**	1	2
M	Concrete supply	Concrete	9	**1**	1	**0**
L	Casting Concrete	Labourer	3	**4**	1	3
	Slab work phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0

MI	Quality	Management	3.5	**0.5**	0.5	**0**
L	Bricks Work					
L	Bricks Laying	Bricklayer	3	**15**	12	**3**
L	Scaffolding	Scaffolder	7	**9**	2	7
MI	Bricks work phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
MI	Submit Project	Management		**1**	1	0

Appendix E4: Trace validation for material flow delays

Type	Activity	Resource	Value	Material	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	**1**	1	0
I	Weekly status report meeting 2	Client	2	**1**	1	**0**
I	Weekly status report meeting 3	Client	2	**1**	1	0
I	Weekly status report meeting 4	Client	2	**1**	1	**0**
I	Weekly status report meeting 5	Client	2	**1**	1	0
I	Weekly status report meeting 6	Client	2	**1**	1	**0**
I	Weekly status report meeting 7	Client	2	**1**	1	0
I	Weekly status report meeting 8	Client	2	**1**	1	**0**
I	Weekly status report meeting 9	Client	2	**1**	1	0
I	Weekly status report meeting 10	Client	2	**1**	1	**0**
I	Weekly status report meeting 11	Client	2	**1**	1	0
I	Weekly status report meeting 12	Client	2	**1**	1	**0**
	Preparation					
L	Site offices installation	Labourer	3	**2**	2	**0**
MI	Project Documentation	Management	6	**4**	4	0
L	Surveying	Labourer	4	**2**	2	**0**
E	Equipment transportation to site	Equipment	12	**1**	1	0
MI	Preparation phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Site settlement					
L	Site Settlement works	Labourer	3	**3**	3	**0**
MI	Site settlement phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Excavation					
L	Excavation Work	Ground workers	4	**7**	7	0
L	Surveying work	Surveyor	3	**7**	7	**0**
MI	Excavation phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Site Surveying					
L	Site Surveying work	Surveyors	4	**1**	1	0
MI	Site Surveying phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Concert work					
M	Concrete supply	Concrete	9	**10**	1	**9**

M	Timber supply	Timber	8	**9**	1	8
M	Steel supply	Steel	12	**13**	1	**12**
L	Joinery Work	Joiner	5	**2**	2	0
L	Casting concrete	Labourer	3	**1**	1	**0**
MI	Concert work phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Formwork					
L	temporary frame building	Semi-skilled	4	**1**	1	0
MI	Formwork phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
L	Steel Work					
M	Steel Reinforcements supply	Steel reinforcement	9	**10**	1	**9**
L	reinforce concrete structures	Labourer	3	**2**	2	0
	Steel work phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Casting concrete for Foundation					
M	Concrete supply	Concrete	9	**10**	1	**9**
L	Casting concrete work	Labourer	3	**2**	2	0
MI	Casting concrete for foundation phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	**5**	5	**0**
L	Joinery Works		5	**7**	7	0
M	Concrete supply		9	**10**	1	**9**
L	Casting concrete		3	**1**	1	0
MI	Columns And reinforcement works phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Ground Work					
M	Sand supply	Sand	9	**10**	1	**9**
L	Sand Work	Sand	3	**7**	7	0
	Compaction Work					
MI	Ground work phase review meeting		5	**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0

MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Ground beams					
L	Joinery work	Joinery	5	**3**	3	0
L	Steel Work	Steel workers	7	**4**	4	**0**
L	Casting Concrete	Labour	3	**1**	1	0
MI	Ground beams phase review meeting		5	**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Ground Work					
L	Sand work	Labourer	3	**1**	1	**0**
L	Compaction work	Other skilled	9	**2**	2	0
MI	Grand work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
	Slab on grade					
L	Joinery work	Joiner	5	**1**	1	**0**
L	Casting Concrete	Labourer	3	**2**	2	0
L	Casting Concrete	Labourer	3	**1**	1	**0**
	Slab on grade phase review meeting					
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Columns Work ground floor					
L	Steel Work	Steel workers	7	**3**	3	0
L	Joinery work	Joinery	5	**2**	2	**0**
M	Concrete supply	Concrete	9	**10**	1	9
L	Casting concrete	Labourer	3	**1**	1	**0**
MI	Columns work ground floor phase review meeting			**1**	1	0
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	**0**
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	0
MI	Client Acceptance	Management	0.5	**0.5**	0.5	**0**
MI	Quality	Management	3.5	**0.5**	0.5	0
	Slab Work					
L	Joinery work	Joiner	5	**2**	2	0
M	Brick supply	Bricks	10	**11**	1	**10**
L	Brick laying	Bricklayer	3	**1**	1	0
L	Steel work	Steel workers	7	**5**	5	**0**
L	Electric work	Electrician	3	**1**	1	0
M	Drainage supply	Drainage	2	**4**	2	**2**
L	Plumbing work	Plumber	2	**1**	1	0
M	Concrete supply	Concrete	9	**10**	1	**9**
L	Casting Concrete	Labourer	3	**1**	1	0
MI	Slab work phase review meeting		5	**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0

MI	Quality	Management	3.5	**0.5**	0.5	**0**
L	Bricks Work		12	**14**	14	0
L	Bricks Laying	Bricklayer	3	**12**	12	**0**
L	Scaffolding	Scaffolder	7	**2**	2	0
MI	Bricks work phase review meeting			**1**	1	**0**
MI	Phase Objectives review	Management	1.5	**0.5**	0.5	0
MI	Match Achievement Objectives	Management	1.5	**0.5**	0.5	**0**
MI	Client Acceptance	Management	0.5	**0.5**	0.5	0
MI	Quality	Management	3.5	**0.5**	0.5	**0**
MI	Submit Project	Management		**1**	1	0

Appendix E5: Trace validation for information flow delays

Type	Activity	Resource	Value	Info	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	3	1	2
I	Weekly status report meeting 2	Client	2	3	1	2
I	Weekly status report meeting 3	Client	2	3	1	2
I	Weekly status report meeting 4	Client	2	3	1	2
I	Weekly status report meeting 5	Client	2	3	1	2
I	Weekly status report meeting 6	Client	2	3	1	2
I	Weekly status report meeting 7	Client	2	3	1	2
I	Weekly status report meeting 8	Client	2	3	1	2
I	Weekly status report meeting 9	Client	2	3	1	2
I	Weekly status report meeting 10	Client	2	3	1	2
I	Weekly status report meeting 11	Client	2	3	1	2
I	Weekly status report meeting 12	Client	2	3	1	2
	Preparation					
L	Site offices installation	Labourer	3	2	2	0
MI	Project Documentation	Management	6	4	4	0
L	Surveying	Labourer	4	2	2	0
E	Equipment transportation to site	Equipment	12	1	1	0
MI	Preparation phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Site settlement					
L	Site Settlement works	Labourer	3	3	3	0
MI	Site settlement phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Excavation					
L	Excavation Work	Ground workers	4	7	7	0
L	Surveying work	Surveyor	3	7	7	0
MI	Excavation phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
MI	Site Surveying					
L	Site Surveying work	Surveyors	4	1	1	0
MI	Site Surveying phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Concert work					
M	Concrete supply	Concrete	9	1	1	0

M	Timber supply	Timber	8	1	1	0
M	Steel supply	Steel	12	1	1	0
L	Joinery Work	Joiner	5	2	2	0
L	Casting concrete	Labourer	3	1	1	0
	Concert work phase review meeting			1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Formwork			2	2	0
L	temporary frame building	Semi-skilled	4	1	1	0
MI	Formwork phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
L	Steel Work		16	4	4	0
M	Steel Reinforcements supply	Steel reinforcement	9	1	1	0
L	reinforce concrete structures	Labourer	3	2	2	0
MI	Steel work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Casting concrete for Foundation					
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete work	Labourer	3	2	2	0
MI	Casting concrete for foundation phase review meeting			1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	5	5	0
L	Joinery Works	Joinery	5	7	7	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete	Labour	3	1	1	0
MI	Columns And reinforcement works phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground Work					
M	Sand supply	Sand	9	1	1	0
L	Sand Work	Sand	3	7	7	0
	Compaction Work					
MI	Ground work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0

MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground beams					
L	Joinery work	Joinery	5	3	3	0
L	Steel Work	Steel workers	7	4	4	0
L	Casting Concrete	Labour	3	1	1	0
MI	Ground beams phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground Work					
L	Sand work	Labourer	3	1	1	0
L	Compaction work	Other skilled	9	2	2	0
MI	Grand work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Slab on grade					
L	Joinery work	Joiner	5	1	1	0
L	Casting Concrete	Labourer	3	2	2	0
L	Casting Concrete	Labourer	3	1	1	0
MI	Slab on grade phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Columns Work ground floor					
L	Steel Work	Steel workers	7	3	3	0
L	Joinery work	Joinery	5	2	2	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete	Labourer	3	1	1	0
MI	Columns work ground floor phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Slab Work					
L	Joinery work	Joiner	5	2	2	0
M	Brick supply	Bricks	10	1	1	0
L	Brick laying	Bricklayer	3	1	1	0
L	Steel work	Steel workers	7	5	5	0
L	Electric work	Electrician	3	1	1	0
M	Drainage supply	Drainage	2	2	2	0
L	Plumbing work	Plumber	2	1	1	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting Concrete	Labourer	3	1	1	0
MI	Slab work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0

MI	Quality	Management	3.5	0.5	0.5	0
L	Bricks Work		12	14	14	0
L	Bricks Laying	Bricklayer	3	12	12	0
L	Scaffolding	Scaffolder	7	2	2	0
MI	Bricks work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
MI	Submit Project	Management		1	1	0

Appendix E6: Trace validation for equipment flow delays

Type	Activity	Resource	Value	Equipment	Actual	Delay
	Weekly status report meeting	Client				
I	Weekly status report meeting 1	Client	2	1	1	0
I	Weekly status report meeting 2	Client	2	1	1	0
I	Weekly status report meeting 3	Client	2	1	1	0
I	Weekly status report meeting 4	Client	2	1	1	0
I	Weekly status report meeting 5	Client	2	1	1	0
I	Weekly status report meeting 6	Client	2	1	1	0
I	Weekly status report meeting 7	Client	2	1	1	0
I	Weekly status report meeting 8	Client	2	1	1	0
I	Weekly status report meeting 9	Client	2	1	1	0
I	Weekly status report meeting 10	Client	2	1	1	0
I	Weekly status report meeting 11	Client	2	1	1	0
I	Weekly status report meeting 12	Client	2	1	1	0
	Preparation					
L	Site offices installation	Labourer	3	2	2	0
MI	Project Documentation	Management	6	4	4	0
L	Surveying	Labourer	4	2	2	0
E	Equipment transportation to site	Equipment	12	13	1	12
MI	Preparation phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Site settlement			4	4	0
L	Site Settlement works	Labourer	3	3	3	0
MI	Site settlement phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Excavation					
L	Excavation Work	Ground workers	4	7	7	0
L	Surveying work	Surveyor	3	7	7	0
MI	Excavation phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Site Surveying					
L	Site Surveying work	Surveyors	4	1	1	0
MI	Site Surveying phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Concert work					
M	Concrete supply	Concrete	9	1	1	0

M	Timber supply	Timber	8	1	1	0
M	Steel supply	Steel	12	1	1	0
L	Joinery Work	Joiner	5	2	2	0
L	Casting concrete	Labourer	3	1	1	0
MI	Concert work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Formwork					
L	temporary frame building	Semi-skilled	4	1	1	0
	Formwork phase review meeting			1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
L	Steel Work		16	4	4	0
M	Steel Reinforcements supply	Steel reinforcement	9	1	1	0
L	reinforce concrete structures	Labourer	3	2	2	0
MI	Steel work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
MI	Casting concrete for Foundation					
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete work	Labourer	3	2	2	0
MI	Casting concrete for foundation phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Columns And reinforcement Works					
L	Steel Works	Steel workers	7	5	5	0
L	Joinery Works		5	7	7	0
M	Concrete supply		9	1	1	0
L	Casting concrete		3	1	1	0
MI	Columns And reinforcement works phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground Work					
M	Sand supply	Sand	9	1	1	0
L	Sand Work	Sand	3	7	7	0
	Compaction Work					0
MI	Ground work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0

MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground beams					
L	Joinery work	Joinery	5	3	3	0
L	Steel Work	Steel workers	7	4	4	0
L	Casting Concrete	Labour	3	1	1	0
MI	Ground beams phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Ground Work					
L	Sand work	Labourer	3	1	1	0
L	Compaction work	Other skilled	9	2	2	0
MI	Grand work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Slab on grade					
L	Joinery work	Joiner	5	1	1	0
L	Casting Concrete	Labourer	3	2	2	0
L	Casting Concrete	Labourer	3	1	1	0
MI	Slab on grade phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Columns Work ground floor					
L	Steel Work	Steel workers	7	3	3	0
L	Joinery work	Joinery	5	2	2	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting concrete	Labourer	3	1	1	0
MI	Columns work ground floor phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
	Slab Work					
L	Joinery work	Joiner	5	2	2	0
M	Brick supply	Bricks	10	1	1	0
L	Brick laying	Bricklayer	3	1	1	0
L	Steel work	Steel workers	7	5	5	0
L	Electric work	Electrician	3	1	1	0
M	Drainage supply	Drainage	2	2	2	0
L	Plumbing work	Plumber	2	1	1	0
M	Concrete supply	Concrete	9	1	1	0
L	Casting Concrete	Labourer	3	1	1	0
	Slab work phase review meeting			1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0

MI	Quality	Management	3.5	0.5	0.5	0
L	Bricks Work		12	14	14	0
L	Bricks Laying	Bricklayer	3	12	12	0
L	Scaffolding	Scaffolder	7	2	2	0
MI	Bricks work phase review meeting		5	1	1	0
MI	Phase Objectives review	Management	1.5	0.5	0.5	0
MI	Match Achievement Objectives	Management	1.5	0.5	0.5	0
MI	Client Acceptance	Management	0.5	0.5	0.5	0
MI	Quality	Management	3.5	0.5	0.5	0
MI	Submit Project	Management		1	1	0

Appendix F1: Combining activities durations and delays in the CPM network

Type	Activity	Resource	Activity duration	Delay	Duration + Delay
	Weekly status report meeting	Client			
I	Weekly status report meeting 1	Client	1d	2	3d
I	Weekly status report meeting 2	Client	1d	2	3d
I	Weekly status report meeting 3	Client	1d	2	3d
I	Weekly status report meeting 4	Client	1d	2	3d
I	Weekly status report meeting 5	Client	1d	2	3d
I	Weekly status report meeting 6	Client	1d	2	3d
I	Weekly status report meeting 7	Client	1d	2	3d
I	Weekly status report meeting 8	Client	1d	2	3d
I	Weekly status report meeting 9	Client	1d	2	3d
I	Weekly status report meeting 10	Client	1d	2	3d
I	Weekly status report meeting 11	Client	1d	2	3d
I	Weekly status report meeting 12	Client	1d	2	3d
	Preparation				
L	Site offices installation	Labourer	2d	3	5d
MI	Project Documentation	Documentation	4d	6	10d
L	Surveying	Labourer	2d	4	6d
E	Equipment transportation to site	Hammer	1d	12	13d
MI	Preparation phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Site settlement				
L	Site Settlement works	Labourer	3d	3	6d
	Site settlement phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Excavation				
L	Excavation Work	Ground workers	7d	4	11d
L	Surveying work	Surveyor	7d	3	10d
	Excavation phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Site Surveying				
L	Site Surveying work	Surveyors	1d	4	5d
	Site Surveying phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d

MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Concert work				
M	Concrete supply	Concrete	1d	9	10d
M	Timber supply	Timber	1d	8	9d
M	Steel supply	Steel	1d	12	13d
L	Joinery Work	Joiner	2d	5	7d
L	Casting concrete	Labourer	1d	3	4d
	Concert work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Formwork				
L	temporary frame building	Semi-skilled	1d	4	5d
	Formwork phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
L	Steel Work				
M	Steel Reinforcements supply	Steel reinforcement	1d	9	10d
L	reinforce concrete structures	Labourer	2d	3	5d
	Steel work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Casting concrete for Foundation				
M	Concrete supply	Concrete	1d	9	10d
L	Casting concrete work	Labourer	2d	3	5d
	Casting concrete for foundation phase review meeting		1d		6d
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Columns And reinforcement Works				
L	Steel Works	Steel workers	5d	7	12d
L	Joinery Works		7d	5	12d
M	Concrete supply		1d	9	10d
L	Casting concrete		1d	3	4d
	Columns And reinforcement works phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d

MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Ground Work				
M	Sand supply	Sand	1d	9	10d
L	Sand Work	Sand	7d	3	10d
	Compaction Work		13d		22d
MI	Ground work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Ground beams				
L	Joinery work	Joinery	3d	5	8d
L	Steel Work	Steel workers	4d	7	11d
L	Casting Concrete	Labour	1d	3	4d
MI	Ground beams phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Ground Work				
L	Sand work	Labourer	1d	3	4d
L	Compaction work	Other skilled	2d	9	11d
	Grand work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Slab on grade				
L	Joinery work	Joiner	1d	5	6d
L	Casting Concrete	Labourer	2d	3	5d
L	Casting Concrete	Labourer	1d	3	4d
	Slab on grade phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
	Columns Work ground floor				
L	Steel Work	Steel workers	3d	7	10d
L	Joinery work	Joinery	2d	5	7d
M	Concrete supply	Concrete	1d	9	10d
L	Casting concrete	Labourer	1d	3	4d
	Columns work ground floor phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d

MI	Quality	Quality	0.5d	3.5	4d
	Slab Work				
L	Joinery work	Joiner	2d	5	7d
M	Brick supply	Bricks	1d	10	11d
L	Brick laying	Bricklayer	1d	3	4d
L	Steel work	Steel workers	5d	7	12d
L	Electric work	Electrician	1d	3	4d
M	Drainage supply	Drainage	2d	2	4d
L	Plumbing work	Plumber	1d	2	3d
M	Concrete supply	Concrete	1d	9	10d
L	Casting Concrete	Labourer	1d	3	4d
	Slab work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
L	Bricks Work				
L	Bricks Laying	Bricklayer	12d	3	15d
L	Scaffolding	Scaffolder	2d	7	9d
	Bricks work phase review meeting				
MI	Phase Objectives review	Phase Rev	0.5d	1.5	2d
MI	Match Achievement Objectives	Achiev. Obj	0.5d	1.5	2d
MI	Client Acceptance	Client Acc.	0.5d	0.5	1d
MI	Quality	Quality	0.5d	3.5	4d
MI	Submit Project	Management	1d	2	3d