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A Lean Approach to Capacity Management in Construction

by

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ABSTRACT

FACULTY OF ENGINEERING AND APPLIED SCIENCE CIVIL AND ENVIRONMENTAL ENGINEERING

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A LEAN APPROACH TO CAPACITY MANAGEMENT IN CONSTRUCTION

By Basil Omar Al-Sasi

Lean construction has not been universally adopted in the UK construction industry and has had little application in heavy construction although there has been a greater uptake in the housing sector. The objectives of the research are to identify the barriers which are preventing the adoption of lean in the construction industry, to investigate suitable lean methodologies for adoption in the construction industry and to provide mechanisms to overcome the obstacles for adoption.

The research has identified a number of factors, both at construction site level and at corporate level, which have prevented the adoption of lean principles. Firstly, the segregation of buying and construction management departments means that buyers consider only the bottom line cost of materials rather than the complete cost to a project. This results in buyers ordering materials in the maximum possible quantities to attract the largest bulk discounts without considering the associated costs such as storage, damage, double handling and cost of holding inventory. Secondly, construction site staffs have a deep-rooted fear of running out of materials and hence prefer to hold large stocks of material on site. This is made worse by the prevailing practice of ordering extra material just in case. Thirdly, high variability in output occurs in construction and where adoption of lean has been attempted, schedules have not been met and there has been an increase in defective work. Finally, the concepts of, cycle time and work scheduling, is not properly understood at site level. The research initially produced a scheduling calculation model based on four methods taken from operational research: least cost; North West corner; Vogel's approximation and longest required time. The model was trialled on a construction site on the University campus. The results showed that when activities were dominated by machines the model performed well but when activities were dominated by people the variability in output made the schedules predicted by the model unworkable. The trials showed that the actual workloads were not always carried out as projected by the model. Following this, a survey was conducted for the investigation and identification of the daily performance variation levels. From the survey, daily weights were assigned for each day to absorb the expected performance variation. The weights were taken into consideration in the production of the on-site material handling schedules on another building at the University campus to check the performance of the model. This showed that the model performed well and that it helped to structure the flow of material on the construction site.

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Glossary of Terms

Activity Based Costing (ABC):	A management accounting system that assigns costs to products based on the amount of resources used.
Batch and queue:	The mass production practice of making large lots of a part and then sending the batch to wait in the queue before the next operation in the production process.
Cycle time:	The time required to complete one cycle of an operation.
Gemba:	Is a Japanese term, meaning the place where the truth can be found. Others may call it the value proposition
Jidoka:	It is a Toyota principle to stop machines from operating if errors occur.
Kaizen:	Continuous, incremental improvement of an activity to create more value with less waste.
Kanban:	The Japanese word for card.
Karoshi:	The Japanese word for death from over work.
Muda:	The Japanese word for waste.
Perfection:	The complete elimination of muda so that all activities along a value stream create value.
Sensei:	This is the Japanese title used to refer to or address a personal teacher with a mastery of a body of knowledge.
Shusa:	A strong team leader in the Toyota product development system.

Chapter One Introduction

1.1 Introduction

The aim of this research is to investigate the applicability of the lean concepts to construction. Lean is a production philosophy that was established by Japanese engineers in the 1950's (Womack and Jones 1990; Egan 1998; Womack and Jones 2003).

The pioneer behind the lean philosophy is engineer Taiichi Ohno who started his career with Toyota in 1932 (Womack and Jones 1990; Womack and Jones 2003; Liker 2004). He introduced the concepts of lean production to enhance the overall equipment effectiveness, reduce production costs and eliminate production defects (Womack and Jones 1990; Liker 2004).

Lean comprises of five concepts: value; value chain; pull; flow and continuous improvement of production processes (Womack and Jones 2003). Value is the fulfilment of a customer's expectation with respect to the specifications and value chain is the producer's obligation to ensure that the customer's requirement is met throughout the production processes (Womack and Jones 2003; Egan 1998). The value and value chain concepts require a continuous flow of material provided by pulling the raw material through the production processes and transforming it into finished goods (Womack and Jones 2003; Egan 1998).

A continuous examination of the production processes is necessary to continually improve production (Eagan 1998).

The lean concepts progressed as a race against the conventional concept of mass production which was based on the philosophy of Henry Ford (Womack and Jones 1990; Liker 2004). Lean and mass production share the same aim of producing volumes for customers, yet they differ in the way in which the production processes are carried out (Womack and Jones 1990). The production processes in mass production are put into place based on the forecasted numbers estimated from previous sales whereas the pace of the production processes in lean production is adjusted to match the actual orders made by customers (Womack and Jones 1990). Mass production is involved in the production of high volumes of goods before any actual demand is made by customers (Womack and Jones 1990). This requires stockpiling of the finished goods in enormous inventories (Womack and Jones 1990). The production of high volumes ahead of time without any purchasing orders made by customers is viewed as a type of waste in lean production (Womack and Jones 1990; Liker 2004). This type of waste is one among many other types of waste perceived and identified by lean production (Liker 2004). The aim to eliminate waste became the main force driving the evolution from the mass production concept into what is known today as lean (Womack and Jones 2003).

Lean manufacturing has developed and expanded over the past 30 years in the car manufacturing industry and it has been accepted by a vast diversity of industries and service sectors (Egan 1998; Womack and Jones 2003). The lean concepts also known as lean thinking, lean production and lean supply produced a number of tools such as just-in-time management, activity based costing (ABC) and six-sigma, which is a statistical quality control based production process, all of which are currently practiced in different businesses and industries (Womack and Jones 2003).

The positive impact of lean on the various industries stimulated interest in people from the project management and construction business sector in the 1990's (Koskela 1992; Egan 1998). Production and construction are similar in the way they utilise machines and labour to transform raw material into outputs whether the processed outputs are goods or buildings (Koskela 1992).

Performance variation is a natural element of production and construction processes, it can be measured, reduced and managed if the roots that are causing the variation are properly identified (Abdelhamid 2003).

Thomas (2000) employed the workflow method to measure labour inefficiency on a weekly basis and concluded that labour inefficiencies are related to interruptions in the normal flow of work available for the contractor to perform.

Thomas et al (2002) suggests that the main aim of lean construction is to improve the overall performance by reducing the variability factor in labour productivity by placing emphasis on developing and refining flexible capacity management practices instead of reducing levels of workflow variability.

Horman and Thomas (2005) believe that ''*Material stockpiles help manage variable conditions of construction by cushioning activities from the variability*'', and when inventory act in this way, they act as a buffer (Horman and Thomas 2005). This necessitates site material management, which is ''*the allocation of delivery, storage,* *and handling, spaces and resources''* (Thomas et al 2005 b). Thomas et al (2005 b) proposed site material management as a technique to stabilise the flow of labour, and to minimise inefficiencies caused by congestion in the working areas and excess material. Thomas et al (2005 a) were inspired by the *''DNA of Toyota''* and highlighted the importance of improving workforce management strategies to address the realities of construction projects, they concluded that *''more research is needed in this part of lean construction to provide data''* (Thomas et al 2005 a).

1.2 Research problem

The construction industry in England provides a lucrative environment for businesses operating in the construction industry. The construction industry is complex in nature but is essentially a service industry transforming a client's vision into a finished facility. However, every industry struggles with obstacles and constraints which are unique to their environment of operation. In the construction industry the obstacles and constraints frequently result in cost and time overruns.

1.3 Research objectives

The objectives of the research are:

- To study the impact of lean techniques on the capacity management of the work processes of construction teams when viewed as a component of flow.
- To provide a methodology for identifying the buffer locations and their capacities for storing materials at the construction site in collaboration with the workers involved.
- To provide a methodology for identifying the locations of supply and to determine the demand of material for each of the selected locations in collaboration with the construction workers.
- To reduce the overall level of variation by managing the daily labour performance output variation within a working weeks perspective.

1.4 Organisation of the report

The report is organised as follows:

Chapter Two Literature Review

The purpose of this chapter is to provide an overview of the relevant literature related to construction and the lean concept to construction in particular and to identify gaps in the knowledge of the application of lean thinking to construction. It looks at the origins of the lean concept in production and discusses the impact of lean on the Japanese way of carrying out production. In addition it reflects the focus of researchers stimulated by the lean concept and discusses the literature of lean construction.

Chapter Three Methodology

This chapter provides an overview of the methodology used for carrying out this research and the reason for selecting it. The methods and techniques adopted for collecting the data are also described and the findings from the field research are described.

Chapter Four Application of the Model

This chapter describes the implementation of the on-site material handling calculation model to the EEE building construction site and the ISVR building construction site at the University of Southampton.

It also provides the analysis obtained from the survey that was carried out while the on-site material handling calculation model was being applied to the EEE building construction site and the ISVR building construction site.

Chapter Five Discussion

In this chapter, the findings from the field research are discussed and a number of deductions are made, which address the findings, with the purpose of improving construction performance.

Chapter Six Conclusions and Recommendations

This chapter reflects on the lessons that have been learned from the research, in terms of the methodology used, and its application in the field research. It summaries the methodology and concludes the research. In addition, it also describes the future work.

Chapter Two   Literature Review

2.1 Introduction

The construction industry in England *''accounts for 8% of the country's GNP''* and *''employs 1.9 million''* with *''an annual turnover of £65bn''* (Kennedy 2001), forming a lucrative environment for the businesses involved in the construction industry. The construction industry, although *''essentially a service industry''* with the role of transforming *''plans and specifications into finished products''*, as explained by Peurifoy and Ledbetter (1985), is *''exceedingly complex and highly individual in character''*. However, every industry struggles with obstacles and constraints which are unique to their environment of operation. In the construction industry the obstacles and constraints frequently result in cost and time overruns, and overall client dissatisfaction (Egan 1998).

Cost overruns are not new to the construction industry as they were reported in projects as long ago as the early 1800's. For example Kennedy (2001) stated that the *''conversion of the Queen House to Buckingham Palace cost architect John Nash his job in 1829 when it turned out at more than 300% over budget.''*

Nowadays, the average costs of overruns on projects in the public sector are within 30% of budget. In the public sector, well over two thirds of projects go over budget and are delayed by around the same proportion (Audit Commission 1997). Another obstruction in the construction industry is labour performance inefficiency. Egan (1998), found that clients are increasingly dissatisfied with the performance of the industry in terms of time and cost which is partly a consequence of Egan's findings that *''labour is used at only 40-60% potential efficiency''*. The Egan report, points out the lean thinking principles required implementations in order to improve the performance of the construction industry. In presenting these principles, Egan drew upon his experience in the automotive industry.

2.2 The Beginning of Lean Production

Lean production dates back to the late 1940's, with the collapse of Toyota's car sales in the United States of America caused by the introduction of the *''Dodge Line''* (Womack and Jones 1990), a financial and monetary contraction policy drafted by

Joseph Dodge to overcome the inflation problem that was present at that time through credit restrictions .

Toyota, although they had managed to decrease the number of workers needed to produce a given volume of vehicles, were still faced with the consequences of the decision to lay off one third of its labour force, which provoked the remaining working force to go on strike. As a result, Toyota's President Kiichiro Toyoda took responsibility for misjudging the market and left the company in 1950. This action created room for change in the organisational culture of Toyota, and the change in culture led to the implementation of Ohno's lean techniques to production in agreement with Toyota's labour Union.

Toyota's organisational culture was influenced by the Japanese culture, which is different from the western culture. In the Japanese culture, managers are willing to take the responsibility for mistakes and resign from their duties as a consequence of their action. The culture of an organisation develops over time and may not be easy to change. The pervasive nature of culture in terms of how things are done here also has a significant effect on organisational processes and the behaviour of staff. *''An ineffective culture may result in a lack of flexibility for or acceptance of, change''* (Mullins 2002).

Kiichiro Toyoda was the person who initiated Toyota's product development system, by introducing a strong team leader (Shusa) into its product development system at a managerial level. Kiichiro had also put in place the Toyota supplier group and the Toyota distribution and sales system, each of which complemented to the new logic of production, known as lean production.

2.2.1 Product Development System

The changes implemented by Ohno to Toyota's organisational culture, resulting in the introduction of the first truly strong chief engineer, Kenya Nakamura at that time who, together with his team were able to reduce the product development cycle time required for replacing car models, to four years.

Product development is the process by which new design ideas are brought from non existence to ownership by customers (Freeman-Bell and Balkwill 1996).

Clearly this process has an effect on all other departments of the organisation, from marketing and market research where the ideas that customers will pay for are identified, through manufacturing where products are actually made (Freeman-Bell and Balkwill 1996).

The people that are in charge of the product development process must have good contact with customers and be efficient at determining what they actually want (Freeman-Bell and Balkwill 1996). In addition, the organisation must constantly review the progress of its new products under development and reject ones which show signs of not being acceptable to the customer (Freeman-Bell and Balkwill 1996). For this reason, good product development means having many products under development and leaving the final choice as late as possible (Freeman-Bell and Balkwill 1996).

Howell and Ballard (1995) explained that the main purpose of the product development process in construction is *''to surface and resolve trade-offs between means and ends, all the way from the product design through facility construction.''* This process necessitates lean design and lean supply to overcome uncertainty and flow variation.

2.2.2 Toyota Supplier Group

Toyota started to decentralise its internal departments and turn them into independent but affiliated businesses in 1949, forming Toyotas first tier of suppliers, comprised of the newly created companies: Nippondenso, Aisin Seiki, and Toyoda Gosei. This had been triggered by the mandate of the American occupation in 1947 to disband firms with an industrial concentration of holdings of which Toyota was one, but this mandate was never enforced.

The action of decentralising the internal departments and turning them into affiliated independent businesses had a positive impact on Toyota, which managed to reduce the unwanted added value into its manufactured vehicles from 75 percent in 1937 to 25 percent by the late 1950's (Womack and Jones 2003).

This improvement encouraged Toyota to continue to increase its supply chain from 4 suppliers into a supply chain of 190 suppliers, with the desire to spread risks and to profit from a lower wage basis for subcontracted parts.

These changes in structure necessitated the implementation for Ohno's target cost concept, by which Toyota determined the value of a given component to the customer and then worked backwards with the suppliers to derive a method to remove enough cost to produce the part at the target cost with an acceptable profit.

By the end of the 1970's Toyota finalised the Just-in-time concept as the governing discipline for its entire supply chain, delivering components through continuous flows in the form of small batches delivered more frequently in response to (Kanban) signals, evolving to what is known nowadays as the Toyota Production System TPS.

(Kanban), the Japanese word for card, is a system for pulling materials through the manufacturing process. It signals *''that work is required and can be done, and therefore that materials are needed''* (Freeman-Bell and Balkwill 1996).

Lamming and Cox (1995) termed the formation of collaborative business supplier partnerships, required for making lean production possible, as lean supply.

2.2.3 Toyota Distribution and Sales System

During the crises of 1950 and based on the banks' demands, Toyota was forced to establish a new company, Toyota Motor Sales, with the role of buying-in all the manufactured vehicles from the Toyota factories, then distributing the finished vehicles through the dealership network to customers. The rationale behind this arrangement was attributed to a fault of the sales department, which was blamed by the banks for coming up with an over optimistic sales forecast. This led to the overproduction of vehicles that year resulting in many being unwanted.

The banker's theory was doubtful because Toyota Motor Company controlled Toyota Motor Sales, but the arrangement did give Shotaro Kamiya, president of the Toyota Motor Sales Company for twenty-five years, more space to manoeuvre in perfecting his *''customers for life''* selling system. It also allowed him to *''think very hard about how to shorten the order cycle to a point very near the day of manufacture so unwanted cars would not be built''* (Womack and Jones 2003).

These thoughts were the first step towards the radical change in the entire Japanese production industry. It changed from the traditional mass production batch and queue push system to the single piece flow Just-in-time pull system. Howell (1999), reports that Japanese engineers were familiar with mass production of cars from their visits to plant in the United States, but whereas US managers saw efficiency, the Japanese saw waste at every turn. As a result of this understanding the waste created from mass production was redefined by the Japanese engineers, from a single form of waste to a broader scope of waste variation.

2.3 Lean Philosophy

The main aim of lean is to understand value and to remove waste (Womack and Jones 1990; Womack and Jones 2003; Bicheno 2004; Liker 2004). Service providers and goods manufactures must understand that value is about providing a service or producing a product that fulfils the consumer's expectation, for a price the consumer is willing to pay. Activities that do not contribute value to a product or a service are waste or, temporarily necessary non value adding activities (Bicheno 2004).
Organisations should try to continually improve the ratio of value adding to non value adding activities. This is achieved by preventing and reducing waste but also by going after value enhancement specifically (Bicheno 2004).
Taiichi Ohno was the person who identified the broader scope of waste variation, the seven wastes. But it was *"Deming who emphasised waste reduction in Japan in the 1950's"* (Bicheno 2004). In all these wastes, the priority is to avoid, only then to eliminate waste and they are:

- The waste created from overproduction.

Producing items for which there are no orders, which generates other wastes such as overstaffing, unnecessary storage and transportation costs because of excess inventory (Bicheno 2004; Liker 2004).

- The waste of waiting.

This is the type of waste which disrupts the process workflow continuity. Workers stand around idle watching an automated machine or waiting for the next processing step, tool, supply and part because of stock outs, lot processing delays, equipment breakdown and capacity bottlenecks (Bicheno 2004; Liker 2004).

- The waste of unnecessary motions or movement.

This type of waste involves the ergonomics of labour at the workplace. It includes any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc.
Also, walking is waste (Bicheno 2004; Liker 2004).

- The waste of unnecessary transport or conveyance.

Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes. This is an activity which does not add value to the end product and customers do not pay to have goods to be moved around (Bicheno 2004; Liker 2004).

- The waste of over processing or inappropriate processing.

Over processing refers to the waste of using one big machine instead of several smaller ones that are capable of producing the required quantity and quality. This discourages operator ownership, leads to pressure to run the machine as often as possible rather than only when needed and encourages general purpose machines that may not be ideal for the need at hand (Bichenco 2004). Also, waste is generated when providing higher quality products than is necessary (Liker 2004).

Inappropriate processing also refers to machines and processes that are not quality capable, causing unnecessary motion and product defects (Bicheno 2004).

- The waste of unnecessary inventory.

This includes waste created from tying up extensive amounts of financial resources in huge bulks of inventories, in the form of finished goods, excess raw material and work in process stockpiles causing longer lead times, damaged goods, transportation and storage costs and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime and long setup times (Bicheno 2004; Liker 2004).

- The waste of defects.

This type of waste involves production of defective parts or correction. Repair or rework, scrap, replacement production and inspection mean wasteful handling time, money and efforts. In addition, defect costs tend to rise the longer they remain undetected (Bicheno 2004; Liker 2004).

In addition to Ohno's seven wastes, there are some other new types of waste which should be considered, such as the waste of unused employee creativity, causing the loss of ideas, skills, and improvements and learning opportunities by not engaging the employees. There is also the waste of materials, energy and water resources. This type of waste has a negative impact on the environment and operation cost (Bicheno 2004).

2.4 Lean Thinking

As a result of the new definition of waste, the lean thinking movement interpreted the Japanese lean production concept as the five principles of lean thinking.

Lean thinking is composed of value, value stream, flow, and the pull and perfection principles (Womack and Jones 2003). This became a way to continually improve performance efficiency, quality, and reduce created waste.

2.4.1 Lean Construction

The lean terminology refers to the lean approach to production, which was introduced by the Toyota Motor Company in the late 1940's. The principles of lean thinking and techniques will be discussed in more details later. The lean concept in its early stages comprised of two basic principles, the principle of continuous flow, for which Toyota used to stop the machines from operating whenever a mistake was discovered so that no bad parts could be passed forward to interrupt the downstream flow (which Toyota calls jidoka), and the pull system as the second principle to assure that only parts actually needed are made (Womack and Jones 2003). The primary purpose of the Japanese lean production concept is to efficiently optimise the corporation's main objective, essentially, increasing the revenues generated from sales. The plan for achieving the determined objective is to gradually eliminate the waste created, (muda), which accompanies production in all its various forms. This is accomplished by utilising the required production resources, solely, on the basis of job orders arising through demands from potential customers. Howell and Ballard (1998) suggest that construction is essentially the design and assembly of objects fixed-in-place, and that consequently construction possesses are, more or less, the characteristics of site production, unique products, and temporary teams.
The choice between lean and traditional management approaches to construction is influenced by the complexity, uncertainty and quickness on the process of construction. Due to the complex nature of the construction industry and the value addition conceived in the lean approach to production, the lean construction concept started to stimulate the interest of academics internationally (Koskela 1992; Howell 1999; Green 1999). These researchers sought to investigate the extent to which Japanese lean production principles could be applied to construction. In order to provide a solid understanding of what the actual desired objective behind the lean construction concept is meant to achieve, it is important to understand the lean thinking principles and techniques.

2.4.2 Lean Thinking in Construction

Lean thinking is composed of value, value stream, flow, and the pull and perfection principles. The perceived value for a specific product or service should be defined from the end customers perspective, so that all the non value activities, often as much as 95 % of the total, can be targeted for removal step by step (Egan 1998).

Businesses that apply the value concept in defining value from the end customer's perspective could reduce waste as previously explored by Toyota's act of improvements in the 1950's (Womack and Jones 2003). Since most businesses depend on numerous suppliers to render a service or produce a product for potential customers, it is important that waste removal is pursued throughout the whole value stream by implementing a lean supply model for the entire supply chain.

The value stream concept, for example, is achieved in the implementation of efficient partnering processes. The starting point is to specify value from the point of view of the customer, then identify the value stream, which is the sequence of processes all the way from raw material to final customer looking at the entire supply chain (Bechinco 2004; Liker 2004).

In a partnership, all members of the supply chain must work together as a team and must not compete against each other as if they were independent entities so that value can be added to the end product (Bechinco 2004; Liker 2004).

The Hurst spit project shows *"that partnering can provide significant benefits for a one-off project without the need for formal agreements"* when the vision for partnering working is applied with sincerity and trust (Brown and Riley 1998).

Hurst spit is a shingle spit located at the eastern end Christchurch bay on the south coast of England (Brown and Riley 1998). It is approximately 2 kilometres long and its seaward end reaches a point approximately 1250 meters from the Isle of Wight. The spit protects the coastal areas of the Solent to the east, both on the mainland and the Isle of Wight from Atlantic storms (Brown and Riley 1998). Due to the threat of extensive damage to property that would occur as a result of the spit being breached over the years, an enhanced stabilisation scheme was developed. Namely, the Hurst Spit Stabilisation Scheme Project (Brown and Riley 1998).

The project was expected to take the form of a traditional civil engineering contract, which often results in conflict of interests arising between the contractor, engineer and client. The project was both land based and maritime, involving marine dredging for gravel and placing it both on and offshore (Brown and Riley 1998). However, an unforeseen delay at the start of the project meant there was a real danger of not completing the work before winter storms, so a partnering approach evolved with successful results (Brown and Riley 1998).The project was completed in accordance to its original finish date, and was considerably under budget with no defects. Although the granting of licenses issued by the central government caused a seven month delay at the beginning of the project, the applied approach resulted in a sharp schedule reduction of 45% and cost savings of 30%.

The fact that the client, engineer, contractor and sub-contractors were committed to work together as a team, led to the success of this project (Brown and Riley 1998). In addition, the client and engineer had established a good basis for the contractor to work with the minimum confrontation and were keen to build on the approach demonstrated by the main contractor (Brown and Riley 1998). Also, the main contractor adopted a policy of paying its sub-contractors when payment was due instead of the commonly adopted pay when paid policy (Brown and Riley 1998). Two other factors were considered to be important for the success of the project. Site meetings were held with all interested parties present, including sub contractors and suppliers (Brown and Riley 1998).

Second, it was agreed that the resident engineer could work with the sub contractors, thus avoiding any defective work being continued while instructions were passed on by the main contractor (Brown and Riley 1998). Therefore, partnering serves as an example for the application of the lean concepts to construction.

Koskela (1992) argued that construction should be viewed as a design process, construction process and other supportive processes such as the project management process, the design management process and the construction management process. The construction process is the most important one and consists of:

1. *''Material process: consisting of the flows of material to the site, including processing and assembling on site.''*

2. *''Work processes of construction teams. The temporal and spatial flows of construction teams on site are often closely associated with the material processes.''*

Egan (1998) suggested that workloads would be managed more efficiently through reorganising given processes to a position that would enable the product designs to flow through the entire value stream without any interference. This is achieved by using the lean thinking techniques and removing obstacles to create flows.

Egan (1998) stated that:

> ''Activities across each firm are synchronised by pulling the product or design from upstream steps just when required in time to meet the demand from the end customer.''

Pulling the flows of the product designs through the entire value stream by means of synchronising activities down the demand stream, necessitates awareness of two elements; dependent events and statistical fluctuation, Goldratt (1993) suggested that *''the maximum deviation of a preceding operation will become the starting point of a subsequent operation''.*

Takt time is the available work time per day divided by the average demand per day, Womack and Jones (2003) suggest that it *''sets the pace of production to match the rate of customer demand''*. The synchronisation of activities is achieved in balancing the work in each step with the work in other steps, so that everyone is working to a cycle time equal to takt time. When it is necessary to speed up or slow down production, the size of the team may be increased or shrunk, but the actual pace of physical efforts is never changed. As a result, continuity of flow is always maintained. Once value is identified and applied throughout the entire value stream and then pulled as a continuous flow, wasted time and efforts are reduced, and the overall performance efficiency is improved throughout the lean cycle (Egan 1998). Continuous improvement, (Kaizen), is initiated as soon as continuity of the lean thinking cycle is maintained, leading to the reduction of variability, uncertainty and complexity (Howell and Ballard 1998).

2.4.3 Variability in Construction Management

Construction, as previously discussed, is a combination of processes in which the construction process combines the material processes, consisting of the flow of materials and the work processes of the construction teams associated with these material processes. Since construction is complex in nature and the applications of the lean concepts to construction are intended to manage the associated characteristics of variability, complexity and uncertainty, London and Kenley (2001) argued that supply chain management was more than simply logistics and operational issues and that strategic supply chain management subsumes logistics.

Agapiou et al (1998) differentiated the logistic management system from the integrated materials management system, relating the former to meeting customers needs through the coordination of materials and information flows that extend from the market place, through the firm and its operations and beyond to suppliers and hence broader in scope and operating at a strategic level.

The concept of the integrated materials management system requires accurate scheduling of materials to programmed delivery dates keyed to actual site layout and storage arrangements (Agapiou et al 1998). It also requires the early involvement of the materials suppliers in the design phase and overall responsibility for the flow of information relating to materials (Agapiou et al 1998). In selecting a method of handling building materials, the materials characteristics such as weight and vulnerability to damage, the method of packaging, the storage on site and the movement to the workplace are all aspects to be considered (Agapiou et al 1998). Hieber and Hartel (2003) conclude that *"the greater the number of different strategies in place in the supply chain, the greater the costs in the supply chain."*

Therefore, it is of significance to identify a single strategy throughout the entire value stream, with the aim to reduce the associated factor of variability on the flow of material supplies.

Synchronisation of activities is required to maintain a continuous flow, through increasing or decreasing work loads or schedule acceleration in the case of construction. Thomas (2000) explained that scheduled acceleration is having more work to perform in the same period of time or having a shorter period of time to perform the same amount of work. Usually it is a combination of the two, and the economic consequences to the contractor relative to labour productivity are realised in losses of labour efficiency, easily within the range of 20 to 45%.

Thomas et al (2003) conducted three studies in which labour was treated as one of the workflows, based on the baseline productivity method, and found that of 909 work hours charged, 672 work hours were inefficiently used. The most significant cause of loss of labour efficiency relates to the labour resource specifically, resulting from insufficient work to perform and overstaffing.

Labour inefficiencies related to overstaffing, could also be identified in the Thames Barrier Project, where the number of operatives rose from 490 to a peak of 1,550; with 450 subcontractors and a total labour force approaching 2,000 (Morris 1987). However Morris (1987) found that some 70 percent of the £329.3 million 'overrun' was due to inflation, 5 percent due to design enhancements, 10 percent to construction difficulties not covered in the contract, but that 15 percent was due to poor productivity, caused by industrial relations problems, poor management or both.

The initial estimated cost of the project in the 1960's was in the range of £13-18 million, whereas the actual cost of the finished project was around £440 million (Morris 1987).

Thomas et al (2003) observations of labour inefficiencies concluded that labour as a flow has received little focus in lean thinking. They suggested that by not including labour as a component of flow, the application of lean principles ignores a potentially large opportunity for cost and schedule improvement. This does not mean that labour should be treated like a commodity but it means that the flow of work could be enhanced by trying to prevent or reduce the waste of unnecessary transport, the waste of unnecessary movement and the waste of waiting.

The reorganisation of the material and work team construction processes, which are highly dependent on the flow of materials, to a position, that would enable the product designs and capacities to flow through the entire value stream, requires the exploration of the lean management techniques. The techniques of lean management should ease the practice of capacity management whenever it is necessary to view labour as a component of flow in construction.

2.4.4 The Techniques of Lean Management

The primary focus of lean is to maintain a continuous cycle of improvement that flows throughout the entire value stream or processes leading to perfection, by making use of lean tools such as the Theory of Constraints and the plan-do-check-act (PDCA) cycle (Bicheno 2004, Liker 2004).

Bicheno (2004) found that the PDCA cycle is a foundation of the Toyota production system and that PDCA sounds simple and is easily glossed over, but if well done is a powerhouse for improvement. Moreover, in the West many organisations are apt to just ''do'' and neglect the P-C-A. In common with the lean construction literature organisations that only do and neglect the remaining steps have ignored the association of lean methods with totalitarian management regimes (Green 1999).

The Theory of Constraints strives to achieve a range of objectives, such as balancing flow. Bicheno (2004) argued that sometimes the Goldratt ideas have been seen as being in conflict to lean operations. In fact, there is remarkable synergy. Possibly the only real conflict is in the use of OPT (computer based finite scheduling package), black-box type, software rather than JIT style visual control and in particular the Theory of Constrains (TOC) principles, which have developed from OPT, have been used by many successful lean organisations, even though they do not use the software.

In order to put the lean concept into practice, the raw materials on a construction site should be pulled from their storage locations in a proportional sequence as required at the actual location of demand, so that value is added to the process. Since the transportation model is constrained in balancing supply to demand, the material flows and associated work team processes in construction could be balanced by making use of this model. Taha (1987) proposed that the model deals with the determination of a minimum-cost plan for transporting a single commodity from a number of sources (e.g., factories) to a number of destinations (e.g., warehouses). The model can be extended in a direct manner to cover practical situations in areas such as inventory control, employment scheduling and personnel assignment. The model can also be modified to account for multiple commodities. Bicheno (2004) translated the Japanese definition of (Gemba) into English as being the place of action and suggested that the (Gemba) way is to go to the place of action and collect the facts. The traditional way is to remain in the office and to discuss opinions. (Gemba) can be thought of in terms of the ''four actuals'': Go to the actual workplace, look at the actual process, observe what is actually happening, and collect the actual data.

2.5 Construction Process Management

Conventional construction management focuses on planning and controlling the outcomes of a project, not on the process function of project activities. Furthermore, conventional project control plans are typically set up to manage projects using a unilateral form of communication, to ensure that the schedule and budget expectations are met (Picard 2004 a). Industrial process control introduces feedback and feed-forward mechanisms for regulating a process (Murril 1991). Feedback is initiated by a comparison of actual with target outputs. Feed-forward is initiated by a comparison of actual with target inputs. Feedback collected from the outcome of implemented project control plans, is necessary for management to decide whether or not to take action and which corrective action to take, *''without corrective actions a project control system becomes merely a cost/schedule reporting system''* (Diekmann and Thrust 1986). Unfortunately conventional project control plans provide basic control data, which are accounting-based outcome measures and usually arrive too late for viable management action (Picard 2004 a).

Koskela (1992) pointed to the production view of construction, which provides the explanation for the possibility of applying inferential statistics, drawing information from sampled observation of construction activity, to the construction process. In manufacturing and service industries, the process forms the basis of a management approach using statistical analysis to measure and improve process performance (Deming 1986). Process-based performance improvement includes:

- Measuring level and variation of the process.
- Identifying and eliminating causes of variation.
- Raising the level of process performance.
- Identifying events that could disrupt the process.

According to Hopp and Spearman (1996), variability results in some or all of the following:

- Buffering of flows.
- Lower resource utilisation.
- Lost throughput.

In the view of process performance measurement and improvement, construction crew member's performance should be compiled into feedback, collected from project activities already carried out. Analysing the collected feedback, helps to identify many of the problems that account for the majority of recurring and random variations and delays in project execution, including factors that cause recurrent imbalances between manpower available and the amount of actual available work resulting in manpower inventory due to conventional estimating, scheduling or work assignment (Picard 2004 b).

Abdelhamid (2003) argued that the effects of variability are buffered through excess inventory, flexible capacity, and/or work-ready backlogs, where the common element between these three approaches to tackle production process variability is that they are all attempts to combat the effects of variability and not to reduce or eliminate variability altogether. ''*Reducing or eliminating the variability that plague production process requires the removal of the root causes of variability*'' using statistical-based methodologies such as six-sigma (Abdelhamid 2003), which provides a structured framework to organise and implement strategic process improvement initiatives. In regards to the statistical-based methodologies, Ballard (2000) criticised the traditional view of control for ''*correcting deviations from plan*'' stating that ''*deviations are expected, but that expectation is not rooted in the idea that variation*

is natural but rather that sin is inevitable''. Howell and Ballard (1996) argue that it is impossible to make good decisions about causes or corrections of deviations, relying only on productivity and progress data, without understanding workflow.
Ballard (1994) recommended the improvement of planning as a solution for enhanced productivity. Improvement of planning must overcome several obstacles common in the construction industry:

- Management focus is on control (preventing bad change) and neglects breakthrough (causing good change).
- Planning is not conceived as a system, but is understood in terms of the skills and talents of individuals who have planning responsibilities.
- Planning is understood in terms of scheduling, and crew level planning is neglected.
- Planning systems performance is not measured.
- Planning failure is not analysed to identify and act on root causes.

Ballard and Howell (1998) suggest that *''30% less labour is needed when planning reliability is above 50%''*, they proposed that *''productivity is often sacrificed for the sake of schedule, but much less often are schedule benefits actually realised''*. Construction process management is interpreted as a lean thinking planning system.

2.5.1 Lean Project Delivery Systems

Ballard and Howell (2003) compared lean project delivery systems (LPDS) to non-lean project delivery, the LPDS virtues being:

- Focus on the production systems.
- Transform, flow and value goals.
- Involve downstream players in upstream decisions.
- Design product and process mutually together.
- Consider all product life stages in the design.

- Carry out activities at the last responsible moment.
- Generate systematic efforts to reduce supply-chain lead times.
- Incorporate learning into project, firm and supply-chain management.
- Align with stakeholders interests.
- Locate and size buffers to perform their function of absorbing system variability.

Tommelein et al (1999) suggested that the setting of flow rates and the sizing of the construction crew should be planned in accordance to the space management techniques. These techniques *''include defining zones and actively coordinating work areas, storage spaces, and traffic paths''* (Tommelein et al 1999). Ballard and Howell (1998) proposed that crew foremen follow the last planner methodology to shield their workers from uncertainty and enable them to inject reliability into their work plans.

2.5.2 The Last Planner System of Production Control

Construction requires that planning and control is done by different people, at different places within the organisation and at different times during the life of a project. Upper management set the organisational objectives, and a person or a group of people within the lower level processes, specify what physical and specific work will be done on a daily basis to meet the objectives and these type of plans has been called *''assignments''* (Ballard 2000). The person or group that produces assignments is called the *''Last Planner''* (Ballard and Howell 1994). The Last Planner production control system provides a framework for management and workers to plan and control daily production assignments (Ballard 1999).
The required procedures for planning are made possible through:

- Production unit control, which coordinates the execution of work within production units such as construction crews.
- Workflow control, causing work to move between production units in a desired sequence and rate. It *''coordinates the flow of design, supply and installation''* through the look-ahead process (Ballard 2000).

Since the key performance measurement of a planning system at the production level is its output quality, the role of the production unit control is to make progressively better assignments to direct workers through continuous and corrective action. The following are some of the critical quality features of an assignment:

- The assignment is well defined.
- The right sequence of work is selected.
- The work selected is practical.

Well defined means that it can be made ready and that the completion of it can be positively determined. The right sequence is that sequence which is consistent with the project schedule and constructability. The right amount is that amount the planners judge their crews capable of carrying out after review of budget unit rates and after examining the specific work to be done (Ballard 2000, 1994). Practical means that all prerequisite work is in place and all resources are available. The planning system performance is measured indirectly without problems, through the results of plan execution (Ballard 2000, 1994). The Last Planner System uses Percent Plan Complete (PPC) as a metric to measure the quality of the commitments made and the reliability of workflow. Percent Plan Complete is the number of completed assignments expressed as a ratio of the total number of assignments made on a weekly basis. Analysis of performance fluctuation can lead to identification of root causes, so improvement can be made in future performance. This requires the identification of the reasons why planned work was not done, preferably by front line supervisors or craftsmen directly responsible for plan execution (Ballard 2000).

The look-ahead process includes a number of tools and techniques such as the activity definition and prototyping of products or processes known as first-run studies, the identification and removal of constraints that prevent the activity from being a sound assignment, pulling work from upstream production units, and matching load and capacity (Ballard and Howell 2003).

The means of expression for the look-ahead process is a schedule of potential assignments planed for 3 to 12 weeks ahead (Ballard 2000). The time period, over which a look-ahead schedule extends, is based on the project characteristics, the reliability of the planning system, and the lead times for acquiring resources, such as, information, materials, labour, and equipment. Ballard and Howell (2003) proposed that resources can tolerate load and have finite capacities, as a result, *"labour, tools, equipment and space are resources but materials and information are not''* (Ballard and Howell 2003). Buffers are needed to absorb *''variability in the flow of materials and information''*, and buffer inventories are reduced by *''reducing variability''* (Ballard 2000). Thomas et al (2002), as previously mentioned, proposed to reduce variability in labour productivity by placing emphasis on developing flexible capacity management practices instead of reducing levels of variability.

2.5.3 Capacity Management in Opposition to the Last Planner System

Ballard (2000) explained that load can be changed to match capacity by accelerating work flow and that capacity can be changed to match load by reducing or increasing resources. Howell et al (2004) criticised the idea of flexible capacity management proposed by Thomas et al (2002), because *''the relevant concept of work-flow reliability is that of work-load predictability and not uniformity of percentage complete or quantities installed''* (Howell et al 2004).

Thomas et al (2004) concluded that without clear and precise definitions and collaborating data, the discussion of Howell et al (2004) adds little value to the debate over lean construction in general and specifically on work flow variability.

Ballard et al (2005) referred to the fact *''that variability cannot be completely eliminated''*, and proposed to *''try to adjust labour flow according to the unplanned variation of work available''* (Ballard et al 2005) by means of resource flexibility.

Ballard et al (2005) suggested the consideration of three procedures to reduce variability in labour productivity, prior to implementing resource flexibility:

- Reduce performance variability.
- Plan alternative assignments for crews on-site, for cases where it is not possible to carry out the given assignments as planned.
- Provide alternative uses of labour time such as for training and providing feedback.

Ballard (in Chaoo et al 1999) proposed that grouping similar work will create a continuous flow of resources in *''moving crews from one area to the next''* (Chaoo et al 1999). Womack and Jones (2003) in the Lantech plant example explained that the production departments were replaced by production cells, four in total, for each type of product. Similar activities required for producing a product within each cell were lined up together to carry out production in a continuous flow.

Ballard explained that in order to avoid repeated mobilisation and demobilisation of resources for any activity, *''an operation should not be started unless it can be finished without interruptions''* (Chaoo et al 1999). This thought is inconsistent with the main lean concept provided by the supporters of the Toyota Production System, which recognises the need for flexibility when switching from one production activity to the other, with the focus on how to reduce the required set up time of machines, and not on how to eliminate the mixing of different production activities (Womack and Jones 2003).

Thomas et al (2005 a) were inspired by the *''DNA of Toyota''* and highlighted the importance of improving workforce management strategies to address the realities of construction projects. Thomas et al (2005 a) proposed that the Last Planner technique *''has perhaps been the most successful use of lean production in construction''* and that there is more to lean production. Other lean techniques include *''inventory management, contracting strategies, supply chain management, and design methods, to name a few''* (Thomas et al 2005 a).

2.5.4 Decoding the DNA of the Toyota Production System

Spear and Bowen (1999) studied the reason that made the decoding of the Toyota Production System so difficult, and *''believe that observers confuse the tools and practices they see on their plant visits with the system itself''*. Companies that have tried to adopt the Toyota Production System were unable to perceive that *''activities, connections, and production flows in a Toyota factory are rigidly scripted''* (Spear and Bowen 1999), yet at the same time recognised that the operations are extremely flexible and adaptable. Activities and processes are continuously challenged and are pushed to a higher level of performance, enabling the company to continually innovate and improve. To understand Toyota's success, it is important to recognise that *''the rigid specification is the very thing that makes the flexibility and creativity possible''* (Spear and Bowen 1999). The key to the Toyota production System is to understand that this system creates a community of scientists. *''Whenever Toyota defines a specification, it is establishing sets of hypotheses that can then be tested''*, using the scientific method (Spear and Bowen 1999). Toyota uses a systematic problem solving process that requires a detailed evaluation of the proposed changes. All operations are arranged in the form of experiments and one rule of improvement, ''*which describes how Toyota teaches the scientific method to workers at every level of the organisation*'' (Spear and Bowen 1999). People during their Toyota plant visits observe the specific practices and tools, and are unable to recognise the associated rules, this is why Spear and Bowen (1999) ''*think of the rules as the DNA of the Toyota Production System*''. The unspoken facts that create the Toyota Production System can be captured in four basic rules, and these rules pilot the ''*design, operation, and improvement of every activity, connection, and pathway for every product and service*'' (Spear and Bowen 1999). The rules are as follows:

Rule 1: ''*Toyota's managers recognise that the devil is in the details*'' (Spear and Bowen 1999). This is why all the different activities of work have to be highly specified to content, sequence, timing, and outcome.

Rule 2: Every customer-supplier connection must be direct, and there must be an instantly recognisable yes-or-no way to send requests and receive responses.

Rule 3: The pathway for every product and service must be simple and direct.

Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organisation.

These rules require that ''*activities, connections, and flow paths have built-in tests to signal problems automatically*'', for which in response, corrective actions are made continuously (Spear and Bowen 1999). This is what makes the seemingly rigid system so flexible and adaptable to the changing conditions.

For example, workers at the Georgetown Kentucky Toyota plant designed a sequence of seven tasks to install the right-front seat into a Camry, all of which are expected to be completed in 55 seconds as the car moves at a fixed speed through a production cell. If the production worker finds himself doing task 6, installing the rear seat bolts, before task 4, installing the front seat bolts, ''*then the job is actually being done differently than it was designed to be done, indicating that something is wrong*'' (Spear and Bowen 1999).

Since the deviation is immediately apparent, worker and supervisor can take action to correct the problem instantly and then ''*determine how to change the specifications or retrain the worker to prevent a recurrence*'' (Spear and Bowen 1999).

2.5.5 Stress and Human Factor Engineering in Lean Construction

Green (1999) in respect to lean thinking argued that (Karoshi) is now in common use amongst Japanese workers to describe sudden deaths and severe stress resulting from overwork. However, such references to the human cost of lean production are once again notable by their absence from the lean construction literature.

Womack (2003) in regards to Toyota's 1994 revamped (Motomachi) plant stated that:

> ''If unacceptable levels of stress and fatigue are discovered, the work team then attempts to improve the activities to redesign jobs and develop simpler operator mechanisms.''

In this case, Toyotas action in measuring fatigue and stress formed a managerial tool which was used for reducing the amount of stress resulting from human efforts in production.

Womack and Jones (2003) found that:

> ''As a result, Toyota estimates that it has reduced the human effort needed to assemble a RAV 4 by 20 percent, compared with the most comparable previous products, and at the same time has reduced the amount of assembly automation, the cost of production tools, and slightly reduced the work pace.''

Production and construction call for machines and labour to process the inputs of raw material into, manufactured goods and building outputs. The difference between production and construction can be found in the struggle over setting the production pace, between machine and labour. In the production line, the pace of machines determines the pace of labour whereas in construction the pace of machines is controlled by the pace of labour. Performance variation is a natural element of production and construction processes, it can be measured, reduced and managed if the roots that are causing the variation are properly identified (Abdelhamid 2003). The performance variation of machines in production lines can be managed more efficiently compared to the variation of construction labour. This is related to the fact that the human element in construction is exposed to a higher level of stress and is more sensitive to fatigue, which causes variation in labour output. A common example is that of a production machine that operates on a just-in-time basis and requires the handler to load and unload the machine manually, in such case, the handler does not control the machines rate. If the amount of buffer inventory at each end of the machine is held small, *''the handler is forced into a lifting fixed pace, to get the parts in and out of the machine''*, this prevents the handler from altering to

meet the work task within the required recovery time (Salvendy 1997). The required recovery time starts to exceed the work times at 65% to 70% of maximum aerobic capacity, all of which are under an hour (Kamon 1975; Scheen et al 1981).
Measurement has shown that chosen workloads by the people who were self-paced on the jobs ran from 25 to 35 % of their maximal aerobic capacities (Rodgers 1978). In order to minimise fatigue caused by carrying out heavy activities, it is important to understand how the required recovery time and work time intersect, so that the job planner can *''design jobs with enough variety in the tasks to let the workers prevent excessive fatigue through alternating them''*, or by breaking up activities into shorter segments to speed recovery (Salvendy 1997). Rohmert (1973) has mentioned that the high level of stress localised in muscles, sustained for 6 to 40 sec, will require very long recovery times.
Muscular stresses caused by carrying out light activities such as static loading, which exceed 8% of maximum voluntary muscle strength and are sustained for more than 20 sec continuously, also require long recovery times (Bjorksten and Jonsson 1977; Hagberg 1981).
''With this in mind'' (Salvendy 1997), the following goals should be set for the design of muscular efforts:

- If a task involves heavy stress on a muscle group, make it as short as possible or reduce the load.
- If a task involves static loading of a muscle group, find ways to reduce the effort time by changing posture.
- Avoid high frequency, high effort tasks.
- Avoid moderate or high efforts that are sustained for 10 to 15 sec before relaxation unless they are done less than once in 5 min.

The manual handling regulations assert these goals, and if properly considered, the application of lean construction would be improved rather than discouraged.
Ballard and Howell (1998) suggested that *''going slow to go fast may be a paradoxical idea for the construction industry, but it is an idea whose time has come''*. It is important to consider statistical performance measurement technique's

within the perspective of human factors engineering, to help in identifying the root causes of variation.

2.6 Summary

In this chapter the literature related to lean thinking and the application of the lean concepts to production has been investigated. The review started with the beginning of lean production and its impact on the Japanese production systems in making the change from push to pull. The lean concepts, techniques and tools were explored and the objective of lean was clarified through arguments taken from the lean literature. The applications of the lean concepts in construction were discussed. It had been found that labour inefficiencies are related to overstaffing. Moreover, it has been suggested that labour should be viewed as a component of flow by placing emphasis on developing flexible capacity management practices instead of reducing the levels of workflow variability. In the construction industry, the material flows are highly associated with the work team processes which could be balanced by making use of, inter alia, the transportation model. This model is constrained in balancing supply to demand and deals with the determination of a minimum-cost plan for transporting a single commodity from a number of sources to a number of destinations. The model can also be extended in a direct manner to cover practical situations in areas such as employment scheduling and personnel assignment. The model can also be modified to account for multiple commodities.

Chapter Three Research Methodology

3.1 Methodology

The research methodology adapted for this investigation was action research. Action research was developed during the 1940s independently in the US and UK by Kurt Lewin (1946) and the Tavistock Institute (Hart and Bond 1995) respectively. Both Lewin and the Tavistock Institute applied action research to address problems in industry. The purpose of action research is to implement, change and generate new knowledge (McNiff 1988). Lewin's original definition of action research included practitioners in a cyclic process of four stages:

- Plan.
- Act.
- Observe.
- Reflect.

Action research differs from conventional pure scientific research in terms of *''promoting change''* into the researched subject (Robson 1993).Therefore, action research was used for this study, to research the applicability of the lean concepts to construction, particularly, researching the impact of lean techniques on the capacity management of the work processes of construction teams when viewed as a component of flow. According to Lewin (1946), action research involves a spiral of cycles of planning, acting, observing and reflecting. The purpose of the planning cycle is to reach a certain objective, which in this study, is to create flow among the construction workers who are closely associated with the flow of materials.

3.2 Research Progression

This research as shown in Figure 3- 1, began with the literature review of the lean concept, philosophy and application in construction. The discussion over the issue of how to reduce variation in construction, helped to identify the need to research the lean techniques and find a way for placing the flow concept effectively into practice.

The structure of the thesis

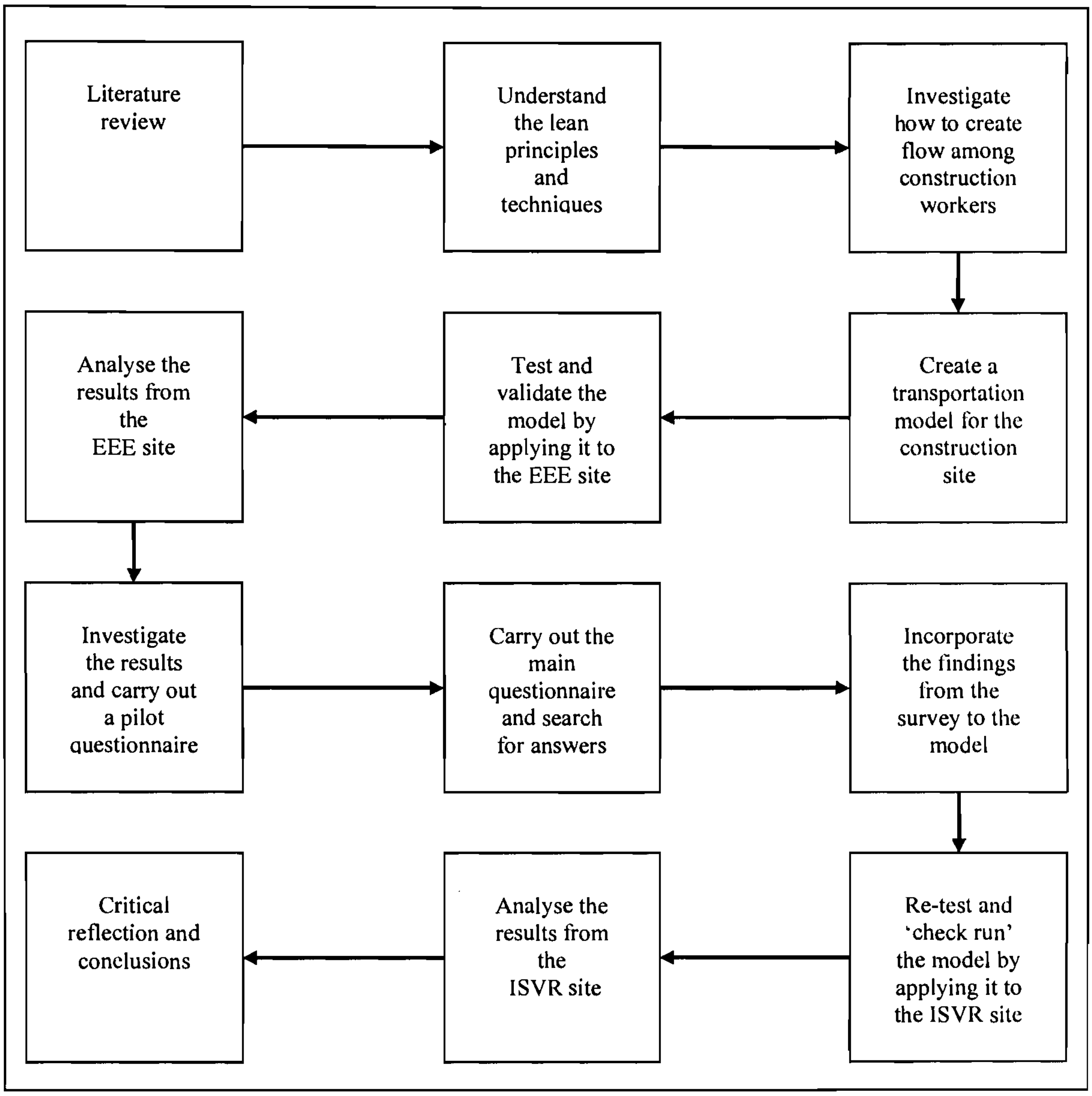

Figure 3- 1: The structure of the thesis

As part of the action research planning cycle, a transportation model was developed. The transportation model was chosen as a technique for placing the flow concept into practice, because its special structure allows the development of a simplex based computational algorithm, which makes use of the primal dual relationships to simplify the computations (Taha 2003).

In addition, it is constrained in balancing supply to demand and the objective of the transportation model is to determine the transportation schedule that minimises the total transportation cost while satisfying supply and demand limits (Taha 2003). Furthermore, the transportation model can be extended to other areas of operation, including among others, inventory control, employment scheduling and personnel assignment (Taha 2003). Other techniques that could have been used for example are models such as the, assignment model, which is actually a special case of the transportation model in which the workers represent the sources and the jobs represent the destinations (Taha 2003). The objective of this model is to determine the optimum assignment of workers to jobs (Taha 2003).

The field trials of the research were conducted on the construction of EEE and ISVR buildings at the University of Southampton. Both buildings used for the model trials were of similar construction. They were concrete framed buildings on piled foundations with monolithic concrete floors. Both buildings are clad with mechanically fixed cladding systems with the EEE building using prefabricated concrete panels and the ISVR building using tiles fixed to clad rails. Internal partitions in both buildings are a mixture of block-work and metal stud.

After the on-site material handling calculation model was developed, the work began with observation and data collection of material flows on the EEE construction project, as part of the action research act cycle. Following data collection the material flow was optimised using the on-site material handling calculation model and the results were implemented on the EEE construction project. Observation and data collection were carried out to assess the impact of the implementation of the changes followed by post implementation interviews with the personnel involved. The process was repeated on the EEE construction project to validate the applicability of the on-site material handling calculation model.

As part of the action research observation cycle, a pilot questionnaire was carried out to search for answers related to the observed outcomes from the application of the on-site material handling calculation model on the EEE construction project. The observations revealed that on some days the output predicted by the model was not achieved. After the pilot questionnaire was analysed, the main questionnaire was carried out and some suggestions for improvement were drawn from the outcome. The suggestions were incorporated into the process and the whole process was repeated on the ISVR construction project for different material and labour flows, as part of the action research reflect cycle. This served as a re-test and check-run of the on-site material handling calculation model. Finally, the outcomes of this research were critically discussed and the final conclusions were drawn.

3.2.1 Identification of the Buffer Locations

As part of the planning cycle, the buffer locations (Buffer1, Buffer2, Buffer3, etc) and the demand locations (A, B, C, etc) within the construction site are identified in collaboration with the construction workers involved, as shown in (Table A 1, Table A 2, Table A 3 and Table A 4). The capacities of the buffer locations and the material demand of each location (A, B, C, etc) are also identified in collaboration with the construction workers.

3.2.2 Data Collection

The cycle time between every buffer (buffer1, buffer2 and buffer3, etc) and each location (A, B, C, etc) was measured and plotted into the transportation timetable, as shown in tables (Table A 1, Table A 2, Table A 3 and Table A 4) . Time was measured for each worker transporting the required material between the buffer locations and the locations of demand, then averaged into cycle time.

3.2.3 Schedule Preparation

After the identification of the buffer locations and the demands of material at each location (A, B, C, etc) in association with the measured cycle times, the schedules were ready to be prepared using the logic of the following methods:

- North West method (see appendix B).
- Least Cost method (see appendix B).
- Vogel Approximation method (see appendix B).
- Ad Hoc method based on the longest transportation time (see appendix B).

<u>Northwest- Corner Method:</u>

This method begins at the *''northwest-corner cell (route) of the tableau''*, and requires the following steps (Taha 2003):

- Step1: Allocate as much as possible to the selected cell, and adjust the associated amounts of supply and demand by subtracting the allocated amount.

- Step 2: Cross out row or column with zero supply or demand to indicate that no further assignments can be made in that row or column. If both a row and a column net zero simultaneously, cross out one only, and leave a zero supply (demand) in the uncrossed-out row (column).

- Step 3: If exactly one row or column is left uncrossed out, stop. Otherwise, move to the cell to the right if a column has just been crossed out or below if a row has been crossed out. Go to step 1 and repeat until all cells are satisfied.

Least-Cost Method:

This method finds a better starting solution by concentrating on the route with the least amount of time needed for transporting a load of material between the buffer and demand locations (Taha 2003). This method starts with assigning as much as possible to the cell with the least amount of time needed to transport a load of material (ties are broken randomly). Then, the satisfied row or column is crossed out and the amounts of supply and demand are adjusted accordingly. If both a row and a column are satisfied simultaneously, only one is crossed out, the same as in the northwest-corner method. Next, look for the uncrossed-out cell with the least amount of time needed to transport a load of material and repeat the process until exactly one row or column is left uncrossed out.

Vogel Approximation Method (VAM):

This method is an enhanced version of the least-cost method that *''generally produces better starting solutions''* (Taha 2003) and it requires the following steps:

- Step 1: For each row (column), determine a penalty measure by subtracting the least required transportation time element in the row (column) from the next least required transportation time element in the same row (column).

- Step 2: Identify the row or column with the largest penalty. Break ties randomly. Allocate as much as possible to the variable with the least required transportation time in the selected row or column. Adjust the supply and demand, and cross out the satisfied row or column. If a row and a column are satisfied simultaneously, only one of the two is crossed out, and the remaining row (column) is assigned zero supply (demand).

- Step 3: If exactly one row or column with zero supply or demand remains uncrossed out, stop.

- Step 4: If one row (column) with positive supply (demand) remains uncrossed out, determine the basic variable in the row (column) by the least-cost method. Stop.

- Step 5: If all the uncrossed out rows and columns have (remaining) zero supply and demand, determine the zero basic variables by the least-cost method. Stop.

- Step 6: Otherwise, go to step 1.

<u>The Ad Hoc method based on the longest transportation time:</u>
This method concentrates on the route with the largest amount of time needed for transporting a load of material between the buffer and demand locations. This method starts with assigning as much as possible to the cell with the largest amount of time needed to transport a load of material (ties are broken randomly). Then, the satisfied row or column is crossed out and the amounts of supply and demand are adjusted accordingly. If both a row and a column are satisfied simultaneously, only one is crossed out, the same as in the northwest-corner method. Next, look for the uncrossed-out cell with the largest amount of time needed to transport a load of material and repeat the process until exactly one row or column is left uncrossed out.

3.2.4 Simulation and Schedule Selection

The flow chart shown in Figure 3- 2, explains how the Excel spreadsheet model works. First, the on-site material handling cycle time values, material capacity values and the material demand values at the locations of demand are entered manually.

Then, supply is balanced to demand in respect to each method.

Finally, the values of the variable parameters are entered manually and the on-site material handling schedules are generated.

Once the schedules are generated, the given results of the schedules can be altered through simulating different scenarios by changing the given variable parameters (working days/ working week, working hours/ working day, number of units X per load, payment/worker/hour and the required number of workers).

Based on the simulation outputs, the best method and its generated schedules are selected.

The flow chart of the on-site material handling calculation model

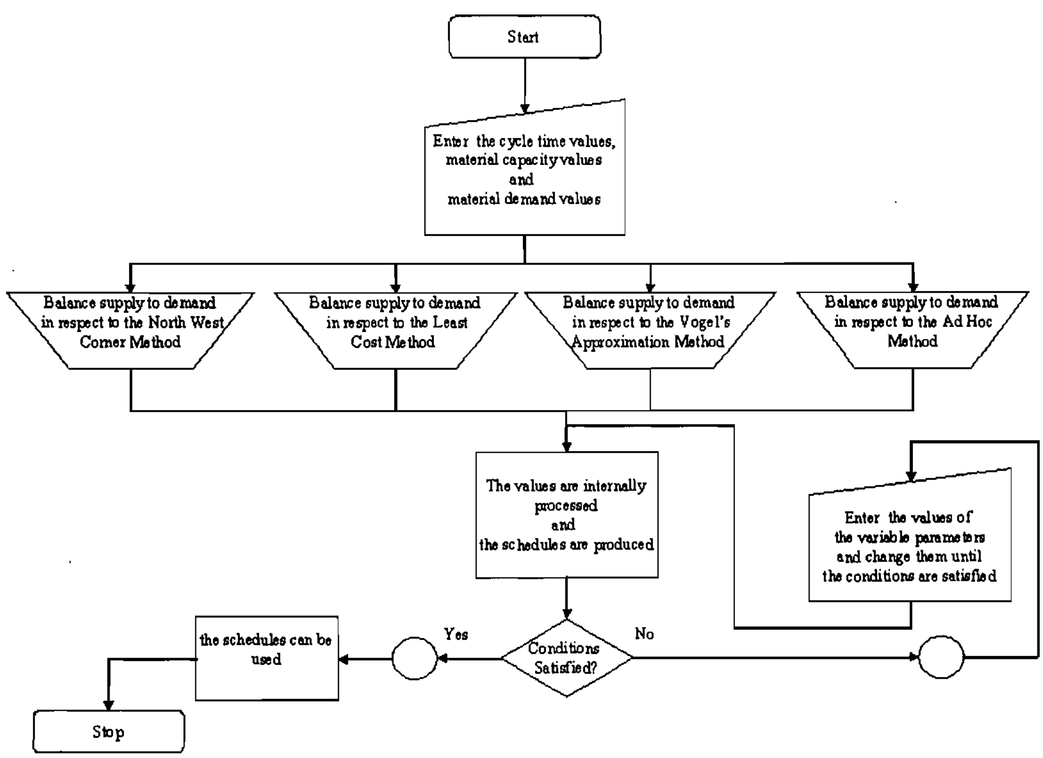

Figure 3- 2: The flow chart of the on-site material handling calculation model

3.2.5 Observation of the Workflow

Once the schedule is ready for implementation, the selected schedules are handed out to the workers, so that the workers can start to supply the predefined demand of materials to the identified locations (A, B, C, D and E) from the identified buffer locations (buffer1, buffer 2 and buffer 3). The actual transported material of all workers is monitored on a weekly basis and a counterbalance account, between the targeted amount and the actual transported amount of material, is maintained.

3.2.6 Plan Reflection

Since the actual performance of the transported material by all workers is measured on a weekly basis, any differences encountered between the actual and target quantities in the weekly supply of material, is documented and altered in the preparation of the following week's material supply schedule. In the experimentation phase of the theoretical model, the differences between the amounts of supply and demand produced from the four methods were treated as a single factor, for which analysis of variance was conducted. *''The one-way model analysis of variance assumes that the observations are normally and independently distributed with the same variance for each treatment or factor level''* (Montgomery and Runger 1994). The null hypothesis for this experiment is satisfied if the calculated F value (Montgomery 1997) retains an allowable level of variation between supplies and demand produced by the four methods, and the analysis is supported by examining the residuals.

3.3 Research Preparation

For the purpose of carrying out this research, a substantial literature review has been conducted to identify gaps in the knowledge. From this a number of theoretical modules have been developed for trial application. A construction project for trials of the theoretical models was identified and consent for undertaking trials was provided by the contractor. The project involved the construction of a new three story building for the University of Southampton. In a site progress meeting, that was held in August 2005, the construction team agreed to utilise the theoretical model for transporting material on site with the commencement of the superstructure activities. Due to the delays that occurred in carrying out the preceding ground slab and simulator pits activities, the superstructure activities were postponed until January 2006.
In order to commence trials an additional project was identified and consent was given by the contractor and the client, which was the University of Southampton, for undertaking trials for testing the theoretical model. This project involved the construction of a new building for the School of Electronics at the University of Southampton. In a meeting that was held in September 2005 with the University's

project supervisor responsible for this particular project, consent was given to utilise the theoretical model to generate on site material schedules for the handling of the concrete panels which are designed to cover the outside of the building. This was used as the first field research trials.

3.3.1 Field Research

The field research involves the construction of a new building for the School of Electronics at the University of Southampton and the main contractor for this particular project was HBG construction Ltd. The on-site material handling calculation model was introduced to the HBG technical services project manager, who was responsible for the construction activities at the construction site of the new School of Electronics. Based on the site layout provided (Figure A 6), the project manager requested scheduling of the tower crane and workers on-site material handling schedules. From the layout it was concluded that the construction site was constrained to only two cranes for carrying out the material handling activities. Furthermore, the construction site had only two storage and drop off areas, which functioned as buffer locations, buffer 1 and buffer 2. The purpose behind the preparation of the crane and workers on-site material handling schedules, at that stage, was to provide the project manager with the insight on how to utilise the model to generate the on-site material handling schedules. A hypothetical generic example was used to introduce the concept to the site staff. The generic example is shown below: In respect to the planning cycle of this example, the buffer locations (Buffer 1, Buffer 2) and the demand locations (A, B, C, D and E) were identified. In the planning cycles, the demand locations have to be identified by the project manager and personnel involved. The capacities of the buffer locations and the material demand of each location for this generic example are shown in (Table 3- 1). In the planning cycles the buffer capacities and the material demand of each location also needs to be identified in collaboration with the project manager.

Capacity/ Demand table

Locations of Demand	Material Demand
A	100
B	150
C	200
D	300
E	100
Buffer Locations	**Buffer Capacities**
Buffer 1	300
Buffer 2	550

Table 3- 1: Capacity/ Demand table for the generic example

The cycle time between every buffer (buffer 1, buffer 2) and each location (A, B, C, D and E) for this generic example are given as shown in (Table 3- 2).

On-site material handling cycle time/ (1 load) in minutes

from	To	A	B	C	D	E
Buffer 1		6	5	3	7	7
Buffer 2		8	7	4	12	6

Table 3- 2: On-site material handling cycle time table for the generic example

The cycle times between every buffer and each location of demand has to be provided by the project manager in the planning cycles. After the identification of the buffer locations and the demands of material at each location (A, B, C, D and E) in conjunction with the measured cycle times, the on-site material handling schedules for the crane and workers were prepared in accordance with the logic of the following methods as shown in (Table A 1, Table A 2, Table A 3 and Table A 4):

- North West Corner method.
- Least Cost method.
- Vogel Approximation method.
- Ad Hoc method based on the longest transportation time.

The on-site material handling calculation model uses 7 steps:

(Step 1): Allocate the material demand and storing capacity as shown in (Table A 1); once the values from (Table 3- 1) are entered into the respective cells, they will automatically appear in the succeeding tables (Table A 2, Table A 3 and Table A 4).

(Step 2): Allocate the cycle times in minutes as shown in (Table A 1); once the values from (Table 3- 2) are entered into the respective cells, they will automatically appear in the succeeding tables (Table A 2, Table A 3 and Table A 4).

(Step 3): Feed the locations of demand in respect to the Least Cost method as shown in (Table A 1).

(Step 4): Feed the locations of demand in respect to the North West Corner method as shown in (Table A 2).

(Step 5): Feed the locations of demand in respect to the Vogel's Approximation method as shown in (Table A 3).

(Step 6): Feed the locations of demand in respect to the Ad Hoc method based on the longest required time as shown in (Table A 4).

(Step 7): Enter the values for the variable parameters from (Table 3- 3) and change them until the conditions are satisfied.

Once the schedules are generated, the given results of the schedules can be altered and optimised through simulating different scenarios by changing the given variable parameters (working days/ working week, working hours/ working day, number of units X per load, payment/ worker/ hour and the required number of workers) and the optimum values for this generic example are shown in (Table 3- 3).

Variable and fixed parameters

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
Number of Workers	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Table 3- 3: Variable and fixed parameters generic example

From (Table 3- 3), the variable parameter (working days/ working week) represent the number of days available to carry out a specific activity within one week. The variable parameter (working hours/ working day) represent the number of hours available to carry out a specific activity within one working day. Based on the simulation outputs, shown in (Table A 7, Table A 8, Table A 9 and Table A 10) the best method and its generated on-site material handling schedule are selected. The actual demand of material is compared to the amount of material to be transported by the given methods, as shown in (Figure A 1).

Whenever it is desired to supply more material through the given methods than actually required, the extra amount of material can be altered by increasing or decreasing the respective (number of units X/ Load) variable parameter given in (Table 3- 3). The difference between the amounts of supply and demand produced from the four methods is treated as a single factor, for which the analysis of variance is conducted. Another way to describe this single factor analysis is as a single factor experiment with four levels of the factor, where the factor is the material scheduling and the four levels are the four different scheduling methods (Montgomery 1997). The degree of freedom for the SS treatment in this example is equal to3, the SSE value is equal to 16 and the total number of degrees of freedom is equal to 19, as shown in (Figure A 2). Montgomery (1997) explained that if the degrees of freedom for SS treatments and SSE add to N-1, the total number of degrees of freedom, *"the Cochran's theorem implies that the mean square value of the treatments and the mean square value of the error are independently chi-square random variables"*. Therefore, *"if the null hypothesis of no difference in treatment means is true"* (Montgomery 1997),the ratio F_0 can be calculated by dividing the mean square value of the treatments by the mean square value of the error.

In order to balance the on-site material handling calculation model within acceptable levels of variation, the calculated F value must not exceed the respective F value that is given in the statistical tables, as shown in (Figure A 2), and the analysis is supported by examining the residuals, as given in (Figure A 3, Figure A 4 and Figure A 5). The choice of schedules to be adopted depends on personal preference and project constraints. The criteria adopted for the selection of the schedules in (Table A 7, Table A 8, Table A 9 and Table A 10) were either:

- To minimise the time to complete activities (weekly working hours, working hours/working week, number of working weeks).
- To maximise production through full utilization of available resources (number of transported units, over production rate).
- To minimise cost (cost of labour).

Taha (2003) suggested that *''in general, the Vogel method yields the best starting basic solution, and the northwest-corner method yields the worst''*.

In this case, the Vogel approximation method projected the best finishing time (57 minutes) compared to the North West corner method (69 minutes), least cost method (68 minutes) and the longest transportation time method (71 minutes).

3.3.2 Discussion

Two supply chains were identified, an internal supply chain in the form of the on-site flows and an external supply chain in the form of the external supplies of material to the construction site. In order to place the pull principle of lean thinking into practice it is important to distinguish the internal supply chain from the external supply chain and to understand that the external supply chain is determined by the internal supply chain. Since each location (A, B, C, D and E) has a different demand for material, the on-site material handling calculation model calculated a different number of loads of material to be transported to the locations of demand. The batch size for each load was constrained to a maximum of 25 units per load and each location of demand had a customised batch size of material per load. This expresses the flexibility of the model and its ability to synchronize resources to meet the different levels of demand at the various locations within the construction site, creating a steady workflow. According to Thomas and Horman (2006) *''flow improvement also encompass equipment availability and labour utilization''*. The model enabled the identification of the required number of working crews needed to carry out the scheduled work, Thomas and Horman (2006) proposed that *''efficient material handling and timely deliveries are important for good productivity, especially on labour- intensive operations''*. This principle if placed into practice would lead to the elimination of negative factors such as over staffing. Researchers such as Glenn Ballard and Owen Matthews from the international group for lean construction IGLC encourage research on issues involved in structuring supply chains for flow, increasing the probability of timely delivery of subassembly components by reducing the number of intersecting flows (the matching or merge bias problem).

3.4 The Theoretical Justification to the Model

The lean principles applied in construction were originally the lean production principles developed by the Toyota Company over the past five decades.
Thomas et al (2005 a) suggest the improvement of workforce management strategies as a solution for *''achieving real gains in industry performance''* inspired by the

''DNA of Toyota'' (Spear and Bowen 1999). Spear and Bowen (1999) studied the reason that made the decoding of the Toyota Production System so difficult, and *''believe that observers confuse the tools and practices they see on their plant visits with the system itself''*. Companies that have tried to adopt the Toyota Production System were unable to perceive that *''activities, connections, and production flows in a Toyota factory are rigidly scripted''* (Spear and Bowen 1999), yet at the same time recognised that the operations are extremely flexible and adaptable. To understand Toyota's success, it is important to recognize that *''the rigid specification is the very thing that makes the flexibility and creativity possible''* (Spear and Bowen 1999).

The specific objective for the on-site material handling calculation model is the determination of a minimum-cost plan for transporting a single commodity from a number of material storage locations, buffers, to a number of destinations within the construction site. This objective puts the lean supply principles into practice as a result of having to reduce the batch size of the supplied material for each load, increasing the frequency of material supply and reducing the required cycle time. This requires that the batch size for each load of material is optimised individually in respect to the available resources. Koskela (1992) recognised that *''the temporal and spatial flows of construction teams on site are often closely associated with the material processes''*. Lamming and Cox (1995) termed the formation of collaborative business supplier partnerships as lean supply. Lean supply is very demanding and in some cases it could lead to economic inequality among partners in a business partnership. London and Kenley (2001) consider the dualist theory as a negative factor responsible for the economic inequality in business partnerships. Lamming (1993) recognised the importance of transparency in the exchange of information between suppliers and believes that the planning of capacity and the operational communication must be undertaken jointly for lean supply to be effective. This model requires the pre-identification of the storage locations and their storage capacities, the identification of the locations of demand and their demand for material, and the calculation of the cycle times between each buffer and each location of demand. These requirements provide the flexibility for the on-site material handling calculation model to manage multiple activities carried out by construction workers.

This on-site material handling calculation model is meant to serve as a lean tool towards the *''workforce management strategies''* suggested by Thomas et al (2005 a).

Chapter Four Application of the Model

4.1 Introduction

The on-site material handling calculation model was utilised at the EEE building construction site and at the ISVR construction site in a systematic method. It was clear that the construction crew member's started to understand the lean philosophy and the positive impact of lean to construction became recognised by them.

Just like in action research, which promotes change in the researched subject, lean aims to focus on the production systems, involve downstream players in upstream decisions, carry out activities at the last responsible moment, generate systematic efforts to reduce supply-chain lead times and incorporate learning into project supply-chain management.

These aims are achieved by going into the actual workplace, (Gemba), looking at the actual process, observing what is actually happening and collecting actual data. However, the person who is carrying out action research must not be ignorant of the Hawthorne effect. Hawthorne is the name of a factory where the effect was first thought to have been observed and described, namely in the Hawthorne works of the Western Electric Company in Chicago, 1924-1933.

Parsons (1974) redefines the *''Hawthorne effect as the confounding that occurs if experimenters fail to realise how the consequences of subjects' performance affect what subjects do''*. The moral of the story referred to as the Hawthorne effect, *''is that people change their behaviour when they think you are watching it''* (Gale 2004).

After the on-site material handling calculation model was being applied to the EEE building construction site a separate pilot study and full survey of construction performance were being carried out to investigate variation between the models prediction and the actual performance outcome.

4.2 EEE Building Construction Site

To enable the field research to be carried out, the HBG project manager responsible for the EEE building construction site delegated the supervision of the study to a senior site manager and suggested using the on-site material handling model for the installation of the cladding panels. The lean concept, the theoretical on-site material handling calculation model and its expected objective were briefly explained to the senior site manager. The on-site material handling schedules were then prepared in a collaborative manner together with the construction crew and in acknowledgement of the Hawthorne effect without any interference in the planning activities. The senior site manager clearly understood the requirements for the model and defined the buffer zones, locations of demand and the material handling cycle times. The physical plans were produced after consent was given by the senior site manager. The on-site material handling schedules were produced to install the exterior panels of the EEE building and the cycle times were inclusive of the panel installation and on-site handling activities. The panel installation and on-site material handling activities were carried out throughout the months of January, February, March and April of the year 2006 and totalled to a sum of 246 working hours or 34 working days. During that period of time a total of 271 panels were fitted to the exterior part of the EEE building with the aid of two construction crews and the utilisation of two tower cranes. As the schedule preparation process was repeated for a number of times the quality of the input information improved throughout the months. This can be the result of a constructive learning cycle amongst the construction crew.

4.2.1 January On-Site Material Handling Schedules

In the first week of January 2006 a number of meetings were held at which the model and its related steps were thoroughly explained to the senior site manager.
The main constraints to the panel installation and on-site handling activities were clearly acknowledged:

- As mentioned previously, the EEE building construction site was constrained to two tower cranes and two drop off and storage areas (Figure A 6).
- The delivery schedule for the panels was fixed by the main supplier and did not permit any changes in schedule (Figure C 4).

This particular constraint restricted the pull principle, which is one of the lean thinking concepts, from being placed into practice for the reason that the external supply of panels was no longer determined by the internal supply chain in the form of on-site material handling activities. This meant that as a result of any delay in the internal supply chain, a bottleneck situation could probably occur at the on-site material storage locations.

Capacity/ Demand table

Locations of Demand	Material Demand	No of Panels
A – East Elevation GL 6-7 level 1		3
B – East Elevation GL 6-7 level 2		2
C – East Elevation GL 6-7 level 3		1
D – East Elevation GL 6-7 level 4		1
		Total 7
Buffer Locations	**Buffer Capacities**	
Buffer 1		7

Table 4- 4: January Capacity/ Demand table

The senior site manager identified the locations of demand from the grid lines shown in (Figure C 3) and assigned the number of panels to the locations of demand as shown in (Table 4- 4). The EEE site layout is simplified into a schematic diagram as shown in (Figure 4- 3), to indicate the basic site layout with particular reference to the buffers and material destinations. In addition, Figure 4- 3 shows how the buffer and material destinations changed throughout the implementation of the model in the succeeding months.

On-site material handling cycle time/(1 load) in minutes

From / To	A	B	C	D
Buffer 1	60	62	67	70

Table 4- 5: January on-site material handling cycle time table

The cycle time required for each panel to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction crew, was determined by the senior site manager based on his experience and not measured as recommended (Table 4- 5).

The Locations of Demand and the Buffer Locations for the EEE Building

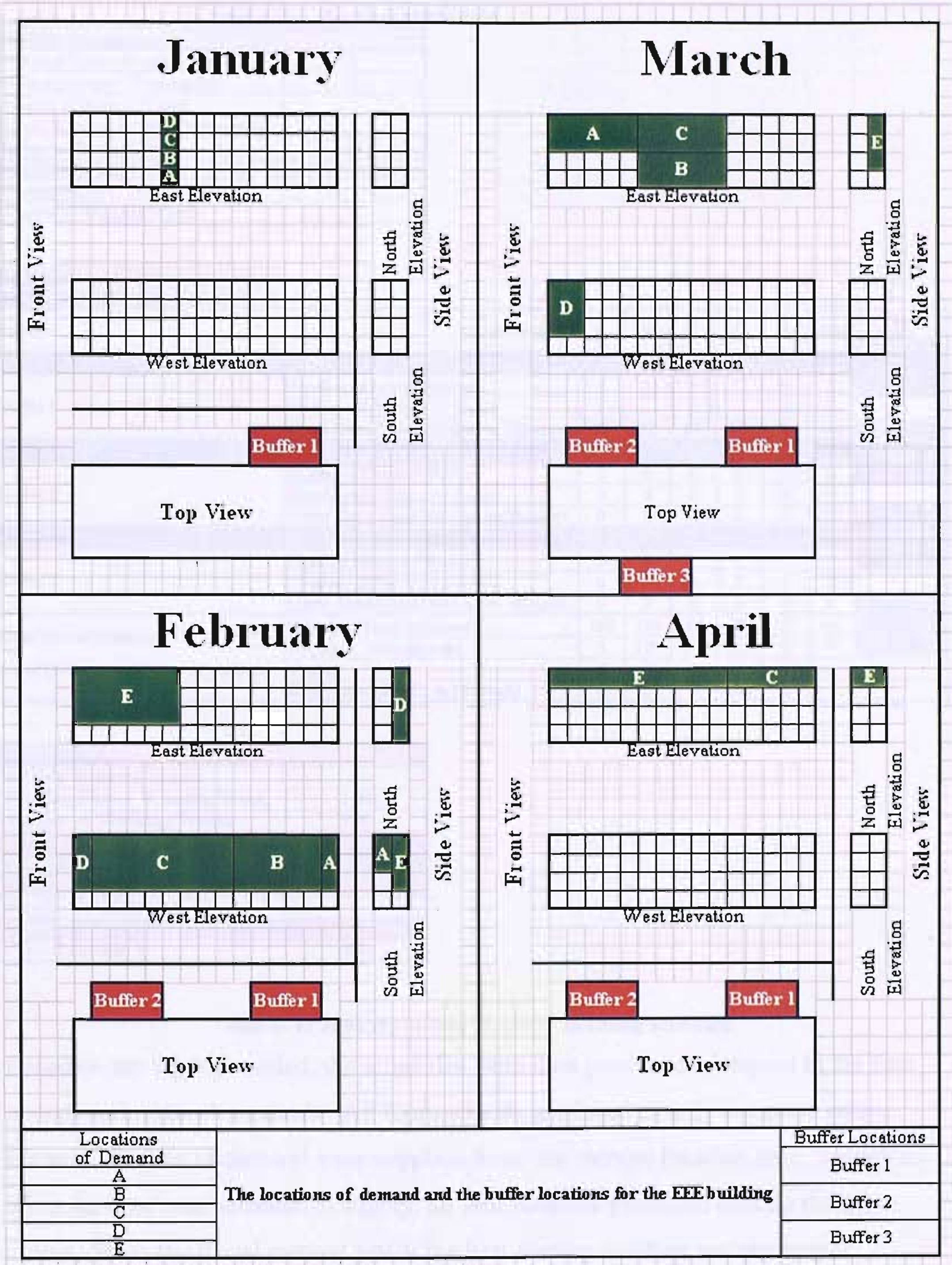

Figure 4- 3: The locations of demand and the buffer locations for the EEE building

EEE January On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	7
Number of Units X / Load	1
No.of (Workers or Group of workers)	1
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	7
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	3	2	1	1	0	7	
	Number of (Units x / 1 Load)	1	1	1	1	0	7	7
	Cycle Time/Load/Worker in Minutes	60	62	67	70	0	441	
Buffer 2	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	180	124	67	70	0	441	
	Required Time (Hours)	3	2.07	1.12	1.17	0	7	
No.of (Workers or Group of workers)	Supply	3	2	1	1	0		7
1	Difference (Supply & Demand)	0	0	0	0	0		0

Time duration:	
Weekly Working Hours	7
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**0%**
Volune Rates:	
Number of Transported Units	7
Over Production Rate(%)	**0.00%**
Cost of Labour £	£70

Table 4- 6: January on-site material handling schedule

Based on the input provided, the schedules were then produced in respect to the four operational research methods. All four methods produced exactly the same output because all areas of demand were supplied from one storage location only. Therefore, when demand was balanced to supply, all four methods produced exactly the same output. Since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 6). The senior site manager assigned one construction crew to carry out the panel installation and handling activities projected by the January material handling schedule, for which 1 working day of 7 working hours within that specific day were required. The job was carried out in accordance with the projected schedule and the target was achieved as planed.

4.2.2 February On-Site Material Handling Schedules

After a successful start in January the methodological approach to the model became clearer to the senior site manager and the physical application of the model to the construction site required less explanation. As a result, the senior site manager became more familiar with the schedule preparation process.

Capacity/ Demand table

Locations of Demand	Material Demand	No of Panels
A – West Elevation GL 1-2 levels 2,3 ,4& 5 and South Elevation GL B-C levels 4&5		24
B – West Elevation GL 2-9 levels 2,3 ,4& 5		24
C – West Elevation GL 9-15 levels 2,3 ,4& 5		21
D – West Elevation GL 15-16 levels 1,2,3 ,4& 5 and North Elevation GL B-C levels 1,2,3,4&5		24
E – East Elevation GL 1-6 levels 3,4&5 and South Elevation GL C-D levels 3,4&5		38
		Total 131
Buffer Locations	**Buffer Capacities**	
Buffer 1 – Areas A&B		48
Buffer 2 – Areas C,D&E		83

Table 4- 7: February Capacity/ Demand table

The senior site manager identified the locations of demand from the grid lines shown in (Figure C 1, Figure C 2 and Figure C 3) and assigned the number of panels to the locations of demand as shown in (Table 4- 7). The buffer and material destinations for February are shown in (Figure 4- 3).

On-site material handling cycle time/(1 load) in minutes

From	To	A	B	C	D	E
Buffer 1		60	61			
Buffer 2				60	61	62

Table 4- 8: February on-site material handling cycle time table

The cycle time required for each panel to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction crew, was determined by the senior site manager based on his experience and not measured as recommended (Table 4- 8).

EEE February On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	19
Working Hours / Working Day	7
Number of Units X / Load	1
No.of (Workers or Group of workers)	1
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	133
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	24	24	0	0	0	48	
	Number of (Units x / 1 Load)	1	1	0	0	0	48	48
	Cycle Time/Load/Worker in Mintues	60	61	0	0	0	2904	
Buffer 2	Number of Loads/Worker	0	0	21	24	38	83	
	Number of (Units x / 1 Load)	0	0	1	1	1	83	83
	Cycle Time/Load/Worker in Mintues	0	0	60	61	62	5080	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Mintues	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	1440	1464	1260	1464	2356	7984	
	Required Time (Hours)	24	24.4	21	24.4	39.3	133	
No.of (Workers or Group of workers)	Supply	24	24	21	24	38		131
1	Difference (Supply & Demand)	0	0	0	0	0		0

Time duration:	
Weekly Working Hours	133
Working Days / Working Week	19.00
Number of Working Weeks	1.00
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**0%**
Volume Rates:	
Number of Transported Units	131
Over Production Rate(%)	**0.00%**
Cost of Labour £	£1,330

Table 4- 9: February on-site material handling schedule

Based on the input provided, the schedules were then produced in respect to the four operational research methods. As in January all four methods produced exactly the same output because each area of demand was connected with one storage location only. Therefore, when demand was balanced to supply, all four methods produced exactly the same output.

As in the previous case, since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 9). The senior site manager assigned one construction crew to carry out the panel installation and handling activities projected by the February material handling schedule, for which 19 working days were required, the equivalent of 3 working weeks. The methodological approach to the model proposed that the on-site handling of material should be scheduled on a weekly basis for a maximum period of 7 working days. It also proposed that the actual performance should be continually reviewed at the end of each week, to aid in taking corrective actions on a more frequent basis. With respect to the Hawthorne effect, no alteration was made to the produced schedule just as the senior site manager has requested. This decision reduced the ability to take instant corrective actions in situations where unpredicted delays could have occurred. The February material handling schedule projected 133 working hours and a total of 19 working days to carry out the specified activities. But the scheduled activities had a delay of 4 days because one of the tower cranes broke down.

4.2.3 March On-Site Material Handling Schedules

After the unpredicted 4 day delay in the February panel installation and on-site handling activities, the senior site manager decided to take some corrective actions in the schedule preparation process.

- Two construction crews were assigned to carryout the March activities as shown in (Table 4- 12).
- The on-site material handling cycle times were increased to buffer any unpredicted delay as shown in (Table 4- 11).

The senior site manager identified the locations of demand from the grid lines shown in (Figure C 1, Figure C 2 and Figure C 3) and assigned the number of panels to the locations of demand as shown in (Table 4- 10). The buffer and material destinations for March are shown in (Figure 4- 3).

Since the buffer zones had a maximum storage capacity of 1 trailer, the stack of panels stored in the trailer located at buffer 1 was exchanged for other panels or approximately 3.5 trailers, buffer 2 for approximately 3.25 trailers and buffer 3 for approximately 3.13 trailers. Also, a mobile crane was used to aid the panel installation.

Capacity/ Demand table

Locations of Demand	Material Demand	No of Panels
A - East Elevation GL 1 – 6 levels 3 & 4	8 x spandrel, 7 x column, 6 x main panels	21
B - East Elevation GL 6 – 11 levels 1 & 2	5 x spandrel, 5 x column, 12 x main panels	22
C - East Elevation GL 6 – 11 levels 3 & 4	16 x spandrel, 10 x column, 17 x main panels	43
D - West Elevation GL 14 – 16 levels 2, 3 & 4	7 x spandrel, 3 x column, 4 x main panels	14
E - North Elevation GL C – B levels 2, 3 & 4	4 x spandrel, 3 x column, 4 x main panels	11
		111 Total
Buffer Locations	**Buffer Capacities**	
Buffer 1 – panels for A near tower crane 1	Trailer 1 = 6 main panels	21 (3.5 trailers)
Buffer 2 – panels for A, B & C near tower cranes 1 & 2	Trailer 2 = 20 combined spandrel & column panels	65 (3.25 trailers)
Buffer 3 – panels for D & E near tower crane 2	Trailer 3 = 8 main panels	25 (3.13 trailers)

Table 4- 10: March Capacity/ Demand table

The cycle time required for each panel to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction crew, was determined by the senior site manager based on his experience and not measured as recommended (Table 4- 11).

On-site material handling cycle time/(1 load) in minutes

From | To	A	B	C	D	E
Buffer 1	360				
Buffer 2	900	150	150		
Buffer 3				240	240

Table 4- 11: March on-site material handling cycle time table

Based on the input provided, the schedules were then produced in respect to the four operational research methods. The Least Cost method, North West corner method and Vogel approximation method produced exactly the same output. The Ad hoc method, based on the longest required time, would have produced a different output because it would have started to allocate material to the cell with the highest cycle time, 900 minutes in this case. But since it is an ad hoc method, changes are permitted and in this case one of the demand areas would have been left unsatisfied if the exact rule was applied. Therefore, when demand was balanced to supply, all four methods produced exactly the same output.

EEE March On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	13
Working Hours / Working Day	8
Number of Units X / Load	1
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	104
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	11	0	0	0	0	11	
	Number of (Units x / 1 Load)	1	0	0	0	0	11	22
	Cycle Time/Load/Worker in Minutes	360	0	0	0	0	1980	
Buffer 2	Number of Loads/Worker	0	11	22	0	0	33	
	Number of (Units x / 1 Load)	0	1	1	0	0	33	66
	Cycle Time/Load/Worker in Minutes	0	150	150	0	0	2475	
Buffer 3	Number of Loads/Worker	0	0	0	7	6	13	
	Number of (Units x / 1 Load)	0	0	0	1	1	13	26
	Cycle Time/Load/Worker in Minutes	0	0	0	240	240	3120	
Over All Performance	Required Time (Minutes)	1980	825	1650	840	720	6015	
	Required Time (Hours)	33	13.8	27.5	14	12	100	
No.of (Workers or Group of workers)	Supply	22	22	44	14	12		114
2	Difference (Supply & Demand)	1	0	1	0	1		3

Time duration:	
Weekly Working Hours	100
Working Days / Working Week	13.00
Number of Working Weeks	0.96
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**4%**
Volume Rates:	
Number of Transported Units	114
Over Production Rate(%)	**2.70%**
Cost of Labour £	£2,000

Table 4- 12: March on-site material handling schedule

As in the previous cases , since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 12). The senior site manager assigned two construction crews to carryout the panel installation and handling activities projected by the March material handling schedule, for which 13 working days were required, the equivalent of 2 working weeks. The methodological approach to the model proposed that the on-site handling of material should be scheduled on a weekly basis for a maximum period of 7 working days. It also proposed that the actual performance should be continually reviewed at the end of each week, to aid in taking corrective actions on a more frequent basis. With respect to the Hawthorne effect, no alteration was made to the produced schedule just as the senior site manager has requested. This decision reduced the ability to take instant corrective actions in situations where unpredicted delays could have occurred. The March material handling schedule projected 100 working hours and a total of 13 working days to carry out the specified activities. But from the scheduled 111 panels only 92 panels were installed in the projected 13 days. A total of 19 panels were left uncompleted, 2 panels in demand area A, 9 panels in demand area C and 8 panels in demand area E.

The key learning from the March schedule preparation process is to maintain a counterbalance account, between the targeted amount and the actual fitted amount of panels.

4.2.4 April On-Site Material Handling Schedules

From the previous on-site material handling implementation, the following key facts became clear to the senior site manager and construction crew:

- The on-site handling of material should be scheduled on a weekly basis for a maximum period of 7 working days.
- The actual performance should be continually reviewed at the end of each week, to aid in taking corrective actions on a more frequent basis.
- Maintain a counterbalance account, between the targeted amount and the actual fitted amount of panels.

Capacity/ Demand table

Locations of Demand	Material Demand	No of Panels
C - East Elevation GL 11 – 16 level 4	6 main panels	6
E – East & North Elevations GL level 4	10 x spandrel, 6 x column	16
		Total 22
Buffer Locations	**Buffer Capacities**	
Buffer 1 – East elevation – Level 4 Main panels	Trailer 1 = 6 main panels	6
Buffer 2 – East & North elevations – spandrel & columns	Trailer 2 = 16 combined spandrel & column panels	16

Table 4- 13: April Capacity/ Demand table

The senior site manager identified the locations of demand from the grid lines shown in (Figure C 2 and Figure C 3) and assigned the number of panels to the locations of demand as shown in (Table 4- 13). The buffer and material destinations for April are shown in (Figure 4- 3).

On-site material handling cycle time/(1 load) in minutes

From	To	A	B	C	D	E
Buffer 1				60		60

Table 4- 14: April on-site material handling cycle time table

The cycle time required for each panel to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction crew, was determined by the senior site manager based on his experience and not measured as recommended (Table 4- 14).

Based on the input provided, the schedules were then produced in respect to the four operational research methods. As before all four methods produced exactly the same output because all areas of demand were supplied from one storage location only. Therefore, when demand was balanced to supply, all four methods produced exactly the same output.

As in the previous cases, since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 15). The senior site manager assigned two construction crews to carry out the panel installation and handling activities projected by the April material handling schedule, for which 1 working day and 6 working hours within that specific day were required. The job was carried out in respect to the projected schedule and the target was achieved as planed.

EEE April On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	6
Number of Units X / Load	1
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	6
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From		To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1		Number of Loads/Worker	0	0	3	0	8	11	
		Number of (Units x / 1 Load)	0	0	1	0	1	11	22
		Cycle Time/Load/Worker in Minutes	0	0	60	0	60	330	
Buffer 2		Number of Loads/Worker	0	0	0	0	0	0	
		Number of (Units x / 1 Load)	0	0	0	0	0	0	0
		Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Buffer 3		Number of Loads/Worker	0	0	0	0	0	0	
		Number of (Units x / 1 Load)	0	0	0	0	0	0	0
		Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance		Required Time (Minutes)	0	0	90	0	240	330	
		Required Time (Hours)	0	0	1.5	0	4	6	
No.of (Workers or Group of workers)		Supply	0	0	6	0	16		22
2		Difference (Supply & Demand)	0	0	0	0	0		0

Time duration:	
Weekly Working Hours	6
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	0%
Ahead of Schedule (% and £)	0%
Volume Rates:	
Number of Transported Units	22
Over Production Rate(%)	0.00%
Cost of Labour £	£120

Table 4- 15: April on-site material handling schedule

It became clear that the senior site manager fully understood the objective behind the lean concept to construction and started to initiate corrective actions that had a positive impact on the job activities that were carried out. It was obvious that the senior site manager was interested and keen on carrying out the same methodological approach for other type of materials at the same construction site. It seemed as if the plans that were generated by the model where more accurate than the plans provided by the senior project manager.

Unfortunately, the senior project manager refused to collaborate further and asked for the field work to stop after the April panel installation and on-site handling activities were carried out (see Figure C 5).

4.2.5 Key Findings from the EEE Building Construction Site

It was found that the on-site material handling calculation model did not perform completely as expected, because fewer panels were installed than initially projected. In order to reduce performance variation, it is important to review the material target schedules more frequently. This would help to take prompt corrective actions more rigorously. It is also helpful to keep a daily record of the actual carried out work to compare it against the scheduled work.

In addition, the reliability of the projected schedules can be enhanced if the cycle times between the buffer and demand destinations are actually measured.

The literature has suggested many root causes for performance variation in construction but it did not suggest values for the expected performance variation in construction. Thus, a questionnaire was designed and carried out to identify values for the expected performance variation levels that could be incorporated into the process for reduction.

4.3 Pilot Survey

The survey used a questionnaire which is shown in appendix E. The pilot survey was targeted at a focus group of 16 specialised senior managers working within the construction industry and the full questionnaire is shown in appendix E, the results of the pilot survey are summarised as follows:

All 16 participants believe that there is a relationship between the workers performance output rate and the specific day of a working week. Furthermore, 14 out of the 16 participants believe that fluctuations in the workers performance output rate varies depending on the specific working day the workers are working on.

In response to the question related to the working day that shows the highest performance output rate of workers, the majority of participants 48%, agreed that Wednesday is the working day with the highest performance output rate of workers. Figure 4- 4 shows the outputs for each workday as a percentage of the weekly output.

Highest Performance Output Rate of Workers

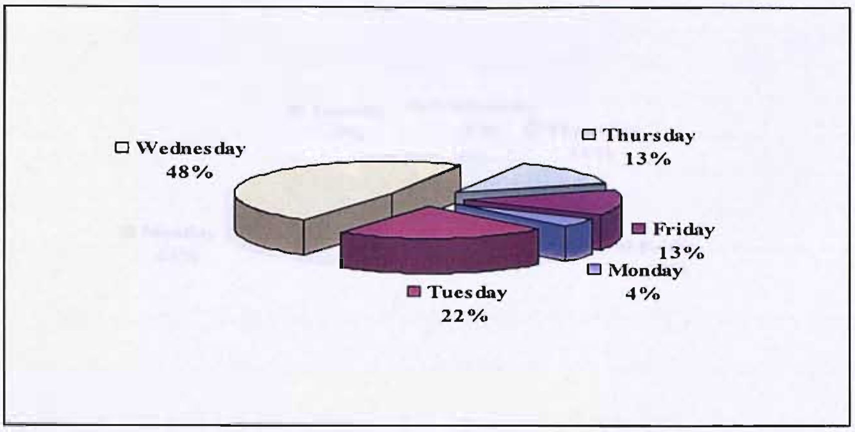

Figure 4- 4: Highest performance output rate of workers

In response to the question related to the working day that shows the lowest performance output rate of workers, the majority of participants 58%, agreed that Monday is the working day with the lowest performance output rate of workers followed by Friday as the second lowest performing day as shown in Figure 4- 5.

Lowest Performance Output Rate of Workers

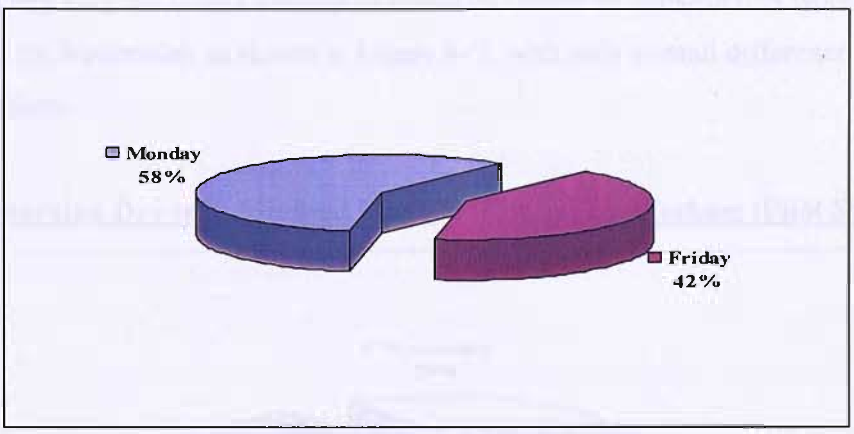

Figure 4- 5: Lowest performance output rate of workers

Additionally, in response to the question related to the working day that shows the highest number of mistakes caused by construction workers, almost half of the participants 44%, agreed that Monday is the working day with the highest number of mistakes caused by workers followed by Friday as the second most error prone working day as shown in Figure 4- 6.

Highest Number of Mistakes Caused By Workers (Pilot Survey)

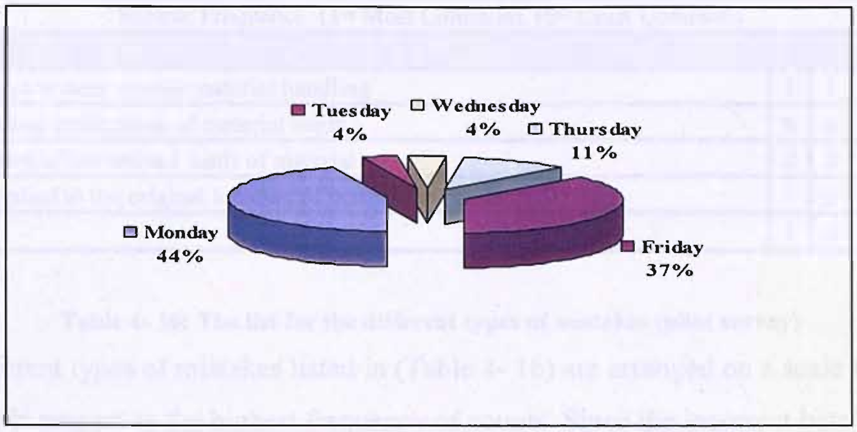

Figure 4- 6: Highest number of mistakes caused by workers (pilot survey)

Since Mondays and Fridays were considered to be the most inefficient working days in terms of output performance rate and number of mistakes, the expectations for targeted scheduled activities should be adjusted accordingly with an acceptable weight to accommodate variation.

In response to the question related to the working day that shows the lowest number of mistakes caused by construction workers, Tuesday is considered as the best working day with the lowest number of mistakes caused by construction workers followed by Wednesday as shown in Figure 4- 7, with only a small difference between them.

Best Working Day with Minimal Mistakes Caused By Workers (Pilot Survey)

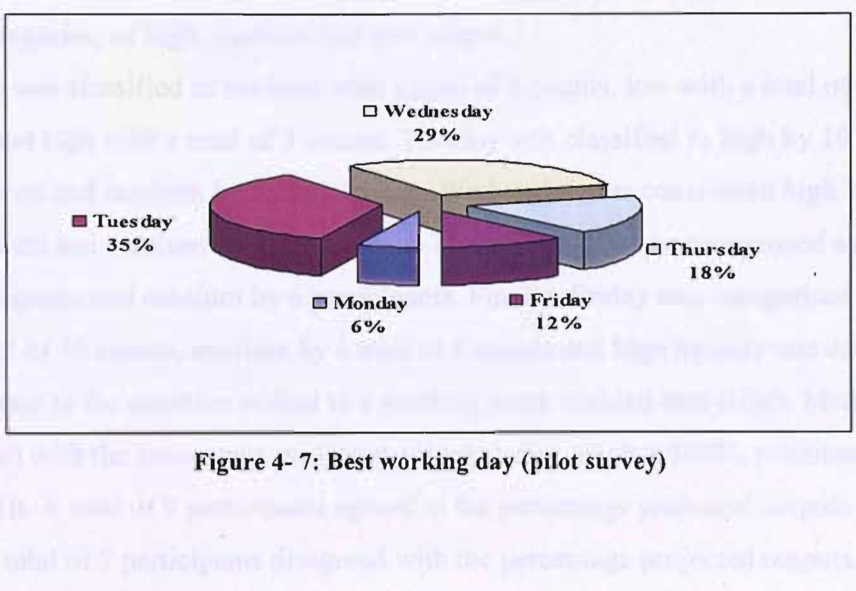

Figure 4- 7: Best working day (pilot survey)

The List for the Different Types of Mistakes (Pilot Survey)

Sample Frequency (1= Most Common), (5= Least Common)						
Type of mistake	1	2	3	4	5	Order
Material damage due to poor on-site material handling	4	1	6	3	1	1
Delays on pre-planned cycle times of material loads	0	6	3	5	0	2
Incorrect batch sizing of predefined loads of material	2	2	7	2	1	3
Material is not supplied to the original location of demand as planned	3	2	4	5	1	4
Other	1	0	2	0	2	5

Table 4- 16: The list for the different types of mistakes (pilot survey)

The different types of mistakes listed in (Table 4- 16) are arranged on a scale from 1 to 5 and in respect to the highest frequency of counts. Since the incorrect batch sizing of predefined loads of material recorded the highest frequency of 7 counts toward category 3, on the 1 to 5 scale, it was placed third in the list.

The delays on pre-planned cycle times of material loads recorded the second highest frequency of 6 counts toward category 2, on the 1 to 5 scale, placing it second in the list. This was followed by, material not being supplied to the original location of demand as planned recording the third highest frequency of 5 counts toward category 4, on the 1 to 5 scale, placed fourth in the list.

On top of the list came material damage due to poor on-site material handling, which recorded the fourth highest frequency of 4 counts toward category 1, on the 1 to 5 scale. Finally, at the bottom of the list came other types of mistakes such as incorrect communication and as suggested by one of the participants and that the labour level is likely to be lower on a Monday because of the subcontract environment.

The eighth question involved the classification of the working days of a week into three categories, of high, medium and low output.

Monday was classified as medium with a total of 8 counts, low with a total of 5 counts and high with a total of 3 counts. Tuesday was classified as high by 10 participants and medium by 5 participants. Wednesday was considered high by 13 participants and medium by 3 participants. Then, Thursday was categorised as high by 10 participants and medium by 6 participants. Finally, Friday was categorised as low by a total of 10 counts, medium by a total of 6 counts and high by only one count.

In response to the question related to a working week divided into (High, Medium, and Low) with the percentage projected outputs being, High = 100%, Medium = 35%, Low = 10. A total of 9 participants agreed to the percentage projected outputs and another total of 7 participants disagreed with the percentage projected outputs.

The information obtained from this survey provided the basis for the full survey, which focused on the identification of the levels of performance output variation for each individual working day within a standard working week.

4.4 Full Survey

Labour performance variation is an inevitable factor for which the expected targeted scheduled activities should be synchronised. The objective of the survey was to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. The survey used a questionnaire which is shown in appendix F. A total of 32 senior managers working within the construction industry participated in the survey and the full questionnaire is shown in appendix F, the results of the full survey are summarised as follows:

In response to the question related to the working day that shows the highest number of mistakes caused by construction workers, the majority of participants 38%, agreed that Monday as well as Friday are the working days with the highest number of mistakes caused by workers as shown in Figure 4- 8.

Highest Number of Mistakes Caused By Workers (Full Survey)

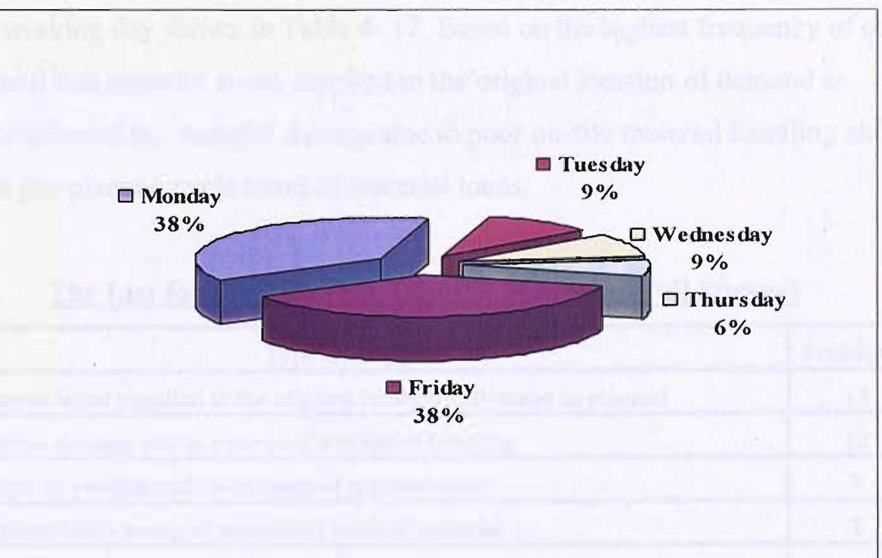

Figure 4- 8: Highest number of mistakes caused by workers (full survey)

Best Working Day with Minimal Mistakes Caused By Workers (Full Survey)

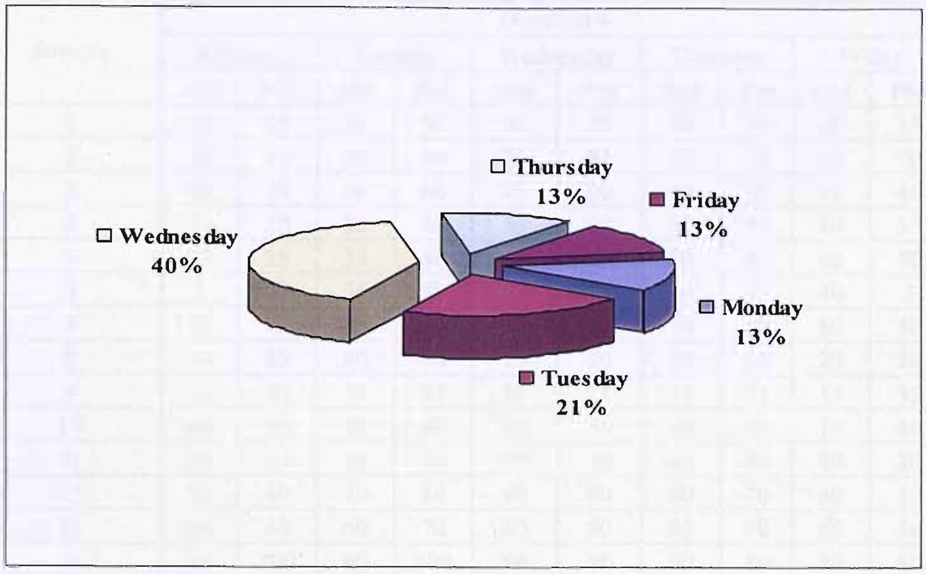

Figure 4- 9: Best working day (full survey)

In response to the question related to the working day that shows the lowest number of mistakes caused by construction workers, it shows that Wednesday is the most efficient working day with the lowest number of mistakes caused by construction workers followed by Tuesday as shown in Figure 4- 9 .

The third question involved the identification of the most frequent occurring mistake within a working day shown in Table 4- 17. Based on the highest frequency of counts, it was found that material is not supplied to the original location of demand as planned. Followed by, material damage due to poor on-site material handling and delays on pre-planned cycle times of material loads.

The List for the Different Types of Mistakes (Full Survey)

Type Of Mistakes	Frequency
1. Material is not supplied to the original location of demand as planned	17
2. Material damage due to poor on-site material handling	12
3. Delays on pre-planned cycle times of material loads	7
4. Incorrect batch sizing of predefined loads of material	2
5. Other	1

Table 4- 17: The list for the different types of mistakes (full survey)

The participants were asked to assign a weight to each shift of each working day as shown in Table 4- 18.

Median and Mode Analysis

Sample	Question 4									
	Monday		Tuesday		Wednesday		Thursday		Friday	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	10	25	35	50	60	75	90	80	45	15
2	30	40	50	60	75	85	95	95	80	70
3	40	50	60	60	75	90	95	90	75	40
4	10	20	30	40	55	65	80	90	80	55
5	20	25	35	40	55	65	75	80	65	50
6	5	20	35	50	60	75	90	65	40	5
7	70	70	80	60	80	80	70	70	80	40
8	50	80	40	70	70	90	30	60	20	30
9	20	50	56	47	58	75	75	75	55	55
10	40	50	70	80	80	50	80	70	70	40
11	30	70	40	60	50	50	60	40	80	20
12	50	60	70	80	90	90	80	70	60	50
13	30	60	60	70	80	90	80	90	60	30
14	80	100	90	100	90	90	90	80	80	50
15	40	60	60	70	80	90	70	80	60	70
16	50	70	70	90	100	100	90	80	60	40
17	20	40	50	50	90	80	70	60	50	10
18	40	40	50	60	70	80	70	60	40	40
19	10	20	30	40	50	40	30	20	10	10
20	30	40	50	60	90	90	70	70	50	50
21	80	80	80	60	60	50	70	80	50	30
22	65	75	81	83	83	85	91	95	98	62
23	60	70	80	80	70	80	70	60	60	50
24	60	60	100	90	100	90	100	80	90	30
25	80	30	100	50	100	50	100	50	70	20
26	30	40	50	50	60	40	50	50	30	20
27	50	55	66	67	74	74	69	68	40	20
28	35	50	55	35	60	65	63	60	50	35
29	75	60	95	85	100	90	95	85	80	40
30	60	45	100	60	100	70	100	50	100	30
31	20	50	39	74	34	69	34	69	34	44
32	75	55	90	90	85	90	70	80	90	80
Median	40	50	60	60	75	80	75	70	60	40
Mode	30	40	50	60	60	90	70	80	80	40
Difference%	25	20	17	0	20	11	7	12	25	0

Table 4- 18: Median and mode analysis

The proportional weight assigned to each shift of each working day indicates the expected amount of scheduled work to be completed within the specified working shift. Whenever these weights are included in the schedules of the succeeding activities, daily output performance variation could be absorbed.

Since the respondents estimates of the level of daily output performance variation varied, a median and mode analysis was carried out to calculate the percentage difference between them. The highest difference found between the median and mode for a working shift was the Monday morning shift and the Friday morning shift both equal to 25 percent as shown in Table 4- 19.

Daily Output Performance Variation Weight Analysis

%	Question 4									
	Monday		Tuesday		Wednesday		Thursday		Friday	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
5	1	0	0	0	0	0	0	0	0	1
10	3	0	0	0	0	0	0	0	1	2
15	0	0	0	0	0	0	0	0	0	1
20	4	3	0	0	0	0	0	1	1	4
25	0	2	0	0	0	0	0	0	0	0
30	5	0	2	0	1	0	3	0	2	5
35	1	0	3	1	0	0	0	0	0	1
40	4	5	3	3	0	2	0	1	3	7
45	0	1	0	1	0	0	0	0	1	0
50	4	5	5	5	2	4	1	3	4	5
55	0	2	1	0	2	0	0	0	1	2
60	3	5	4	8	6	0	2	5	5	1
65	1	0	1	0	0	3	0	1	1	0
70	1	4	3	5	4	3	9	6	2	2
75	2	1	0	0	2	3	2	1	1	0
80	3	2	4	4	5	4	4	8	6	1
85	0	0	0	1	1	2	0	1	0	0
90	0	0	2	3	3	10	5	3	2	0
95	0	0	1	0	1	0	3	2	0	0
100	0	1	3	1	5	1	3	0	2	0
Median	40	50	60	60	75	80	75	70	60	40
Mode	30	40	50	60	60	90	70	80	80	40
Diff%	25	20	17	0	20	11	7	12	25	0
Daily Maximum% by Shift	Monday		Tuesday		Wednesday		Thursday		Friday	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
	30	40	50	60	60	90	70	80	80	40
Daily Maximum%	Monday		Tuesday		Wednesday		Thursday		Friday	
	35		55		75		75		60	

Table 4- 19: Daily output performance variation weight analysis

The Monday morning shift recorded a modal value of 30% and a frequency of 5 counts at 30 percent, on a scale between 0%-100 percent. The modal value 30% was assigned to buffer the output performance variation expected in a Monday morning shift as shown in Table 4- 19. Then, the Monday afternoon shift recorded a frequency of 5 counts at 40, 50 and 60 percent and a median value of 50%, on a scale between 0%-100 percent. The modal value 40% was assigned to buffer the output performance variation expected in a Monday afternoon shift.

Further on, the median value was identical with the modal value in the Tuesday afternoon shift as well as in the Friday afternoon shift. The output performance variation buffer weights for both shifts were assigned on the basis of the modal value. Finally, the output performance variation buffer weights for the remaining daily working shifts were assigned on the basis of the modal value.

The frequency counts for the remaining working shifts were not identical with the median value but were identical with the modal value. The daily output performance variation buffer weights, assigned to each shift of each working day within a standard working week, are presented in the form of a distribution as shown in Figure 4- 10.

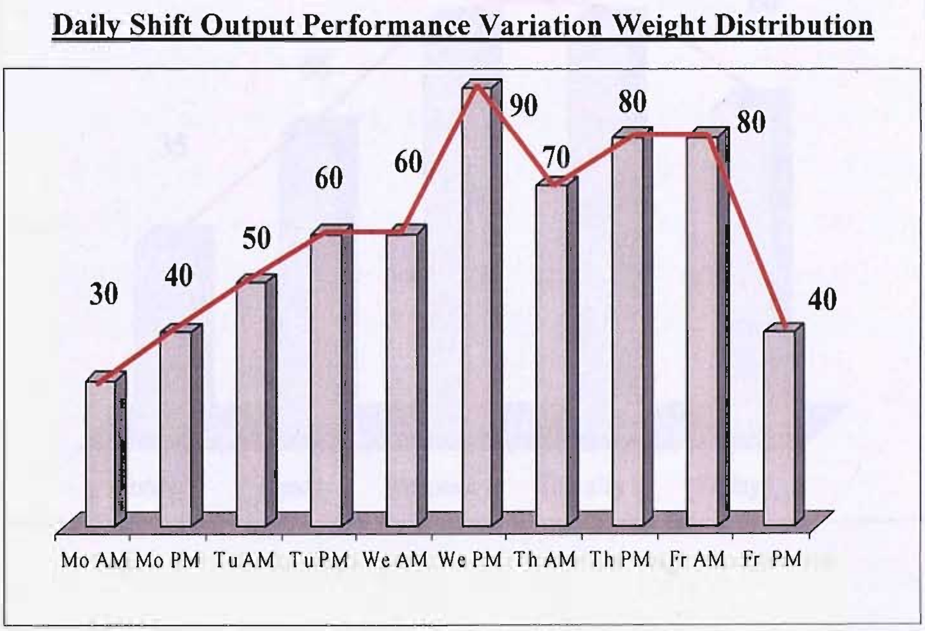

Figure 4- 10: Daily shift output performance variation weight distribution

From the daily shift output performance variation weight distribution (Figure 4- 10), a number of key points were identified:

- The Wednesday afternoon shift has the highest expected output performance rate for completing targeted and scheduled work activities with a rate of 90 percent.

- Since the Wednesday afternoon shift has the highest expected output performance rate, it is recommended that new activities or activities that require a learning curve should be carried out on the Wednesday afternoon shift.
- The overall average expected output performance rate for the entire week equals 60 percent. This rate is equal to the maximum efficiency limit suggested by the Eagan (1998) report.
- The Monday morning shift is the most inefficient working shift.
- Monday in general is the most inefficient working day (see Figure 4- 11).

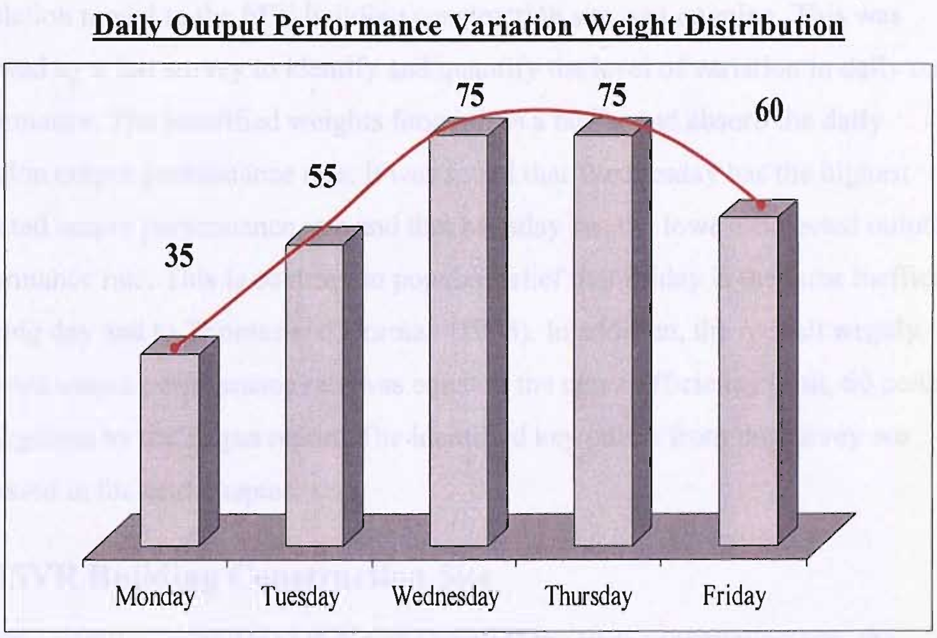

Figure 4- 11: Daily output performance variation weight distribution

Thomas and Horman (2006) proposed a *''four-day, ten hour work week''* while providing the contractor with *''a makeup day (Friday) without overtime pay''*. Since Monday is the most inefficient working day of the week, the proposed idea could be enhanced by considering Monday as the makeup day rather than Friday. In addition, only the Friday afternoon shift has a low expected output performance rate, whereas on the other hand, the Friday morning shift has a high expected output performance rate. Thus, the Friday morning shift should be utilised effectively.

Articles and reports have been published describing the effects of scheduled overtime (Thomas and Raynar 1997), poor material management and vendor relations (Thomas and Sanvido 2000), construction changes (Thomas and Napolitan 1995; Hanna et al 1999a; Hanna et al 1999b), disruptions (Thomas and smith 1990; Thomas and Oloufa 1995; Horner and Talhouni 1993), and wasteful workforce management practices (Thomas et al 2003). The workforce management deficiencies identified by Thomas et al (2003) included insufficient work to perform, over staffing and ineffective use of work teams. These deficiencies have been shown to impact labour productivity negatively (Thomas and Horman 2006).

4.4.1 The Summary of the Survey

A pilot survey was carried out whilst the application of the on-site material handling calculation model to the EEE building construction site was ongoing. This was followed by a full survey to identify and quantify the level of variation in daily output performance. The identified weights function as a buffer and absorb the daily variation output performance rate. It was found that Wednesday has the highest expected output performance rate and that Monday has the lowest expected output performance rate. This is contrary to popular belief that Friday is the most inefficient working day and to Thomas and Horman (2006). In addition, the overall weekly expected output performance rate was equal to the upper efficiency limit, 60 percent, as suggested by the Eagan report. The identified key points from the survey are discussed in the next chapter.

4.5 ISVR Building Construction Site

With the practical experience that was gained at the EEE construction site, the preparation for the field research at the ISVR building construction site took place in July 2006 and it was suggested to use the on-site material handling model for the installation of the tiles. Emphasis was given to maintain a daily performance measurement record of the total number of tiles installed. This measurement gave an insight on performance variation within the duration of a working week.
After the systematic approach of the on-site material handling calculation model was explained to the site engineer, the actual schedules were then prepared in a collaborative manner together with the construction workers and in consideration of the Hawthorne effect without any interference in the planning activities from the

researcher. The site engineer clearly understood the requirements for the model and defined the buffer zones, locations of demand and the material handling cycle times. The physical plans were produced after consent was given by the site engineer. The on-site material handling schedules were produced to install the exterior tiles of the ISVR building and the cycle times were inclusive of the tile installation and on-site handling activities. The tile installation and on-site material handling activities were carried out throughout the months of August and September of the year 2006 for a period of 5 weeks. During that period of time a total of 3989 tiles were fitted to the exterior part of the ISVR building with the aid of four construction workers. The tile installation and on-site material handling activities also included the installation of the window tiles and corner tiles.

4.5.1 August On-Site Material Handling Schedules

In the first week of August 2006 a number of meetings were held at which the model and its related steps were thoroughly explained to the site engineer. Initial times and quantities were calculated and used for the tile installation and handling activities, this gave a rate for the day which was monitored for 2 days to see if it was correct (see Figure D 5). The actual performance measured for the construction workers was slower than projected. Consequently, the cycle time required for each batch of tiles to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction workers was adjusted. A key improvement in the activities carried out at the ISVR building construction site, compared to the EEE building construction site, was the implementation of the pull principle. In contrast with the activities carried out at the EEE building construction site, the external supply of tiles was determined by the internal tile installation and handling activities. Another positive improvement was the reduction of on-site material storage and the number of buffer zones. Initially the intention was to use two storage locations but after the actual testing of the model and the obtained output only one buffer zone was used.

Capacity/ Demand table

Locations of Demand	Material Demand
A	1646
B	1774
Buffer Locations	**Buffer Capacities**
Buffer 1	3420

Table 4- 20: August Capacity/ Demand table

The site engineer identified the locations of demand, located at the North elevation and the East elevation, from the grid lines shown in (Figure D 1 and Figure D 3) and assigned the number of tiles to the locations of demand as shown in (Table 4- 20).

On-site material handling cycle time/ (1 load) in minutes

From	To	A	B
Buffer 1		49	45

Table 4- 21: August on-site material handling cycle time table

The cycle time required for each batch of tiles to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction workers, was determined by the site engineer based on his experience and not measured as recommended (Table 4- 21).

Based on the input provided, the schedules were then produced in respect to the four operational research methods. All four methods produced exactly the same output because all areas of demand were supplied from one storage location only. Therefore, when demand was balanced to supply, all four methods produced exactly the same output.

As in the previous case , since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 22). The site engineer assigned four construction workers to carry out the tile installation and handling activities projected by the August material handling schedule. In addition, the batch size of tiles was constraint to a maximum number of 5 tiles per load and the performance of workers was measured as shown in (Table 4- 23).

ISVR August On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	7
Working Hours / Working Day	6
Number of Units X / Load	5
No.of (Workers or Group of workers)	4
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	42
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	103	111	0	0	0	214	
	Number of (Units x / 1 Load)	4	4	0	0	0	856	3424
	Cycle Time/Load/Worker in Minutes	49	45	0	0	0	2511	
Buffer 2	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	1262	1249	0	0	0	2511	
	Required Time (Hours)	21	20.8	0	0	0	42	
No.of (Workers or Group of workers)	Supply	1648	1776	0	0	0		3,424
4	Difference (Supply & Demand)	2	2	0	0	0		4

Time duration:	
Weekly Working Hours	42
Working Days / Working Week	7.00
Number of Working Weeks	1.00
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**0%**
Volume Rates:	
Number of Transported Units	3,424
Over Production Rate(%)	**0.12%**
Cost of Labour £	£1,680

Table 4- 22: August on-site material handling schedule

The August material handling schedule projected 42 working hours and a total of 7 working days, 6 hours per working day, to carryout the specified activities. From the scheduled 3,420 tiles, only 2,232 tiles were installed, the equivalent of 65% of the targeted quantity. The actual working days exceeded the projected number of working days by a total of 1 additional working day and 7 non productive working days.

ISVR August On-Site Material Handling Performance Measurement

Day	Date	Tiles	Cause of delay
Friday	11/8/2006	265	
Monday	14/8/2006	265	
Tuesday	15/8/2006	265	
Wednesday	16/8/2006	265	
Thursday	17/8/2006	180	
Friday	18/8/2006	0	Workers didn't work
Monday	21/8/2006	0	Rail rework
Tuesday	22/8/2006	0	Rail rework
Wednesday	23/8/2006	553	
Thursday	24/8/2006	229	
Friday	25/8/2006	0	Workers didn't work
Monday	28/8/2006	0	Bank holiday
Tuesday	29/8/2006	0	Weather
Wednesday	30/8/2006	25	
Thursday	31/8/2006	0	Weather
Friday	1/9/2006	185	

Table 4- 23: August on-site material handling performance measurement

Among the 7 wasted working days, 2 days were wasted because the workers did not carry out any tile installation and handling activities, 2 days were wasted because the external rails, to which the tiles are fitted to, needed to be reworked. A further 2 days were wasted because of the rainy weather conditions and 1 day was wasted because it was a bank holiday.

4.5.2 September On-Site Material Handling Schedules

From the previous on-site material handling implementation, a number of points were identified for further investigation:

- Monotonous job activities had an impact on the performance of workers, which requires further investigation.
- From the wasted working days listed in (Table 4- 23), Fridays appeared to be less productive, which requires further investigation.

Capacity/ Demand table

Locations of Demand	**Material Demand**
C	473
D	1284
Buffer Locations	**Buffer Capacities**
Buffer 1	1757

Table 4- 24: September Capacity/ Demand table

The site engineer identified the locations of demand, located at the South elevation and the West elevation, from the grid lines shown in (Figure D 2 and Figure D 4)and assigned the number of tiles to the locations of demand as shown in (Table 4- 24).

On-site material handling cycle time/ (1 load) in minutes

from	**To**	**C**	**D**
Buffer 1		45	49

Table 4- 25: September on-site material handling cycle time table

The cycle time required for each batch of tiles to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction workers, was determined by the site engineer based on his experience and not measured as recommended (Table 4- 25).

Based on the input provided, the schedules were then produced in respect to the four operational research methods. All four methods produced exactly the same output because all areas of demand were supplied from one storage location only. Therefore, when demand was balanced to supply, all four methods produced exactly the same output.

ISVR September On-Site Material Handling Schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	4
Working Hours / Working Day	6
Number of Units X / Load	5
No.of (Workers or Group of workers)	4
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	24
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	0	0	59	64	0	123	
	Number of (Units x / 1 Load)	0	0	2	5	0	438	1752
	Cycle Time/Load/Worker in Minutes	0	0	45	49	0	1448	
Buffer 2	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	0	0	664	784	0	1448	
	Required Time (Hours)	0	0	11.1	13.1	0	24	
No.of (Workers or Group of workers)	Supply	0	0	472	1280	0		1,752
4	Difference (Supply & Demand)	0	0	-1	-4	0		-5

Time duration:	
Weekly Working Hours	24
Working Days / Working Week	4.00
Number of Working Weeks	1.00
Behind schedule (% and £)	**0%**
Ahead of Schedule (% and £)	**0%**
Volume Rates:	
Number of Transported Units	1,752
Over Production Rate(%)	**-0.28%**
Cost of Labour £	£960

Table 4- 26: September on-site material handling schedule

As in the previous case, since the Vogel method yields the best starting solution and the output schedules produced by all four methods are identical, the Vogel method's output was chosen as shown in (Table 4- 26). The site engineer assigned four construction workers to carry out the tile installation and handling activities projected by the August material handling schedule. In addition, the batch size of tiles was constraint to a maximum number of 5 tiles per load and the performance of workers was measured as shown in (Table 4- 27).

ISVR September On-Site Material Handling Performance Measurement

Day	Date	Tiles	Cause of delay
Monday	4/9/2006	315	
Tuesday	5/9/2006	NOT SCHEDULED	
Wednesday	6/9/2006	288	
Thursday	7/9/2006	577	
Friday	8/9/2006	577	

Table 4- 27: September on-site material handling performance measurement

The September material handling schedule projected 24 working hours and a total of 4 working days, 6 hours per working day, to carryout the specified activities. The schedule produced also projected a shortage of material at location C and D for the last batch enabling outputs to be determined in advance. Thus, the projected shortage of material, one tile at location C and 4 tiles at location D were made up from the last load of material installed. From the scheduled 1,757 tiles, all 1,757 tiles were installed, the equivalent of 100% of the targeted quantity and no delays occurred. The main concern for this particular case for evaluating the performance of the model is that the construction workers might have felt that their performance was being watched by the site engineer.

The September schedules also included the scheduling of the corner tiles and window tiles, as mentioned earlier (see Figure D 5).

ISVR Window Tiles On-Site Material Handling Performance Measurement

Day	Date	Elevation	Level	Windows	No. of windows
Wednesday	20/9/2006	East	2	W36, W37	2
Thursday	21/9/2006	West	2,3	W38,W39	2
Friday	22/9/2006	North	1,2	W4,W5,W30,W31	4
Monday	25/9/2006	East	1	W13,W14	2
Tuesday	26/9/2006	North	1	W1,W2,W3	3
		South	1	W24.1,W24.2	2
Wednesday	27/9/2006	North	1	W5, W6,W7	3
		East	1	W9	1

Table 4- 28: Window tiles on-site material handling performance measurement

The mitred window tiles required some additional rework because the wrong dimensions of the window tiles were provided to the supplier. Therefore, the mitred window tiles were bigger in size. The installation, handling and rework activities for the mitred window tiles, were estimated at a rate of, completing 5 windows per working day and the performance was measured as shown in (Table 4- 28).

4.6 Summary

The model was applied to the EEE building construction site and the ISVR building construction site for a period of 6 month. During that period of time, positive feedback was received from both construction sites (see Figure C 5 and Figure D 5). While the on-site material handling calculation model was being applied to the EEE building construction site a survey of construction performance was carried out. The objective of the survey was to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variations. These daily variation weights should be incorporated into the process by anticipating a lower output rate compared to scheduled work. Thus, project managers should plan for the best and expect the worst. The model was then applied to the ISVR building construction site as a check-run, after the variation weights were incorporated into the process. In addition, a number of key points were identified for further investigation. These key points are discussed in the next chapters.

Chapter Five Discussion

5.1 Introduction

The daily expected output performance variation weights are presented on a control chart. In addition, the sigma quality level is calculated to provide a better sense of the magnitude of the process performance failure. Further on, the causes for the loss of labour efficiencies are discussed. Then some fundamental site material management principles are discussed. This is followed by the discussion of the Hawthorne effect and the awareness for labour empowerment.

5.2 Performance Variation and Control Limits

Deming (1986) stressed that because all things vary, statistical methods are required to control quality or defect rates. Most important is to understand the two different types of variation prior to attempting to address quality problems. These are common cause and special cause variation also known as chronic and sporadic variations. The former is an inherently random source of variation and addressing it involves a major change in the basic process and operating procedures. The latter is an unusual but controllable source of variation that requires a correction to bring the process or procedures back to its normal levels. Deming recommended that special cause variation be addressed first before addressing common cause variation.

The daily output performance variation weight distribution illustrates common cause and special cause variation. Due to variations in the input of the labour daily performance rate, the expected output performance rate for the entire week will also be variable.

Figure 4- 11 shows the daily expected output performance rate assuming it follows a normal distribution where the ideal target is represented by the mean value 60 percent. This normality assumption is justified because the inputs are mutually independent which allows the central limit theorem to be invoked. Montgomery (2001) explained that the sum of mutually independent random variable approaches normality as the number of variables become larger. Unfortunately, it is difficult to find a large number of independent participants that meet the profile of a project manager with the

calibre and insight knowledge on issues related to labour output performance variation.

A total of 32 senior managers working within the construction industry participated in the labour output performance variation survey and *"in many cases of practical interest, if* $n \geq 30$*, the normal approximation will be satisfactory regardless of the shape of the population"* (Montgomery and Runger 1994).

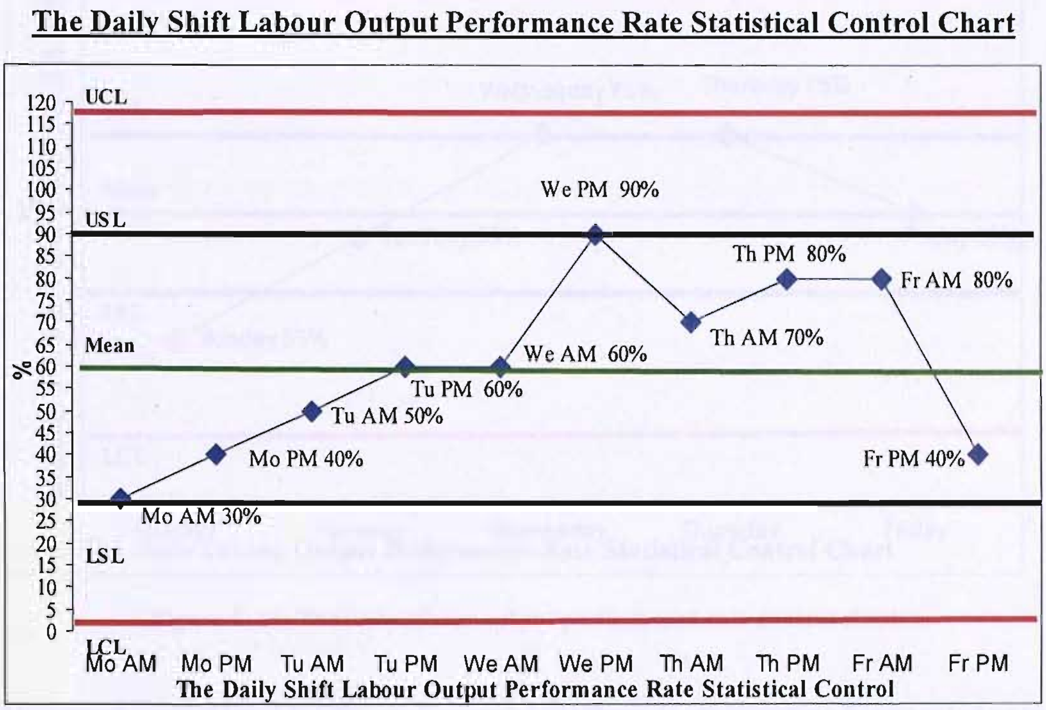

Figure 5- 12: The daily shift labour output performance rate control chart

The statistical charts shown in Figure 5- 12 and Figure 5- 13 are used to isolate common from special cause variation. The upper and lower control limits (UCL and LCL) shown are functions of the process mean, process range and the standard deviation of the measured data obtained from Figure 4- 10 and Figure 4- 11 consecutively, with the assumption that the measured data is normally distributed. A process is considered under statistical control if all the data points fall within the LCL and UCL. Data points falling outside the LCL and UCL are caused by special cause variation, which is apparently inevitable because of unpredicted incidents such as equipment break down and physical labour fatigue which has a negative impact on the performance outcome resulting in performance variation (Abdelhamid 2003). Montgomery (2001) explained that even the ideal mean value itself is subject to a variation or shift of up to ± 1.5sigma and the upper and lower specification limits (USL and LSL) are chosen independently of the normal distribution.

The Daily Labour Output Performance Rate Statistical Control Chart

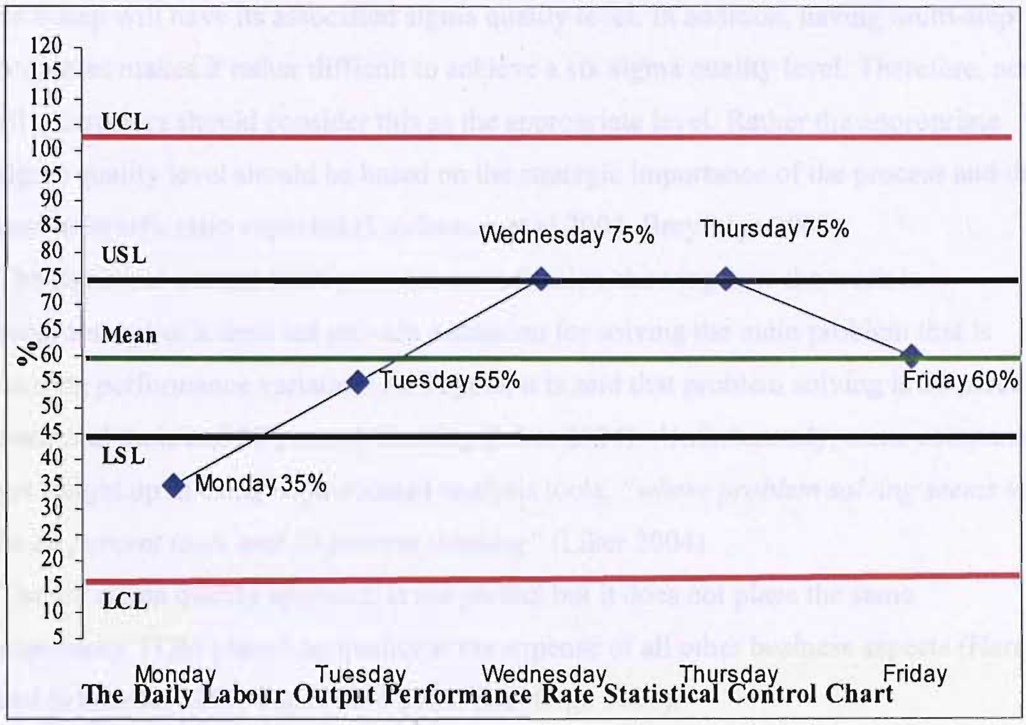

Figure 5- 13: The daily labour output performance rate control chart

The upper control limit for the performance of labour in construction is expected to be around 60 percent and the lower control limit around 40 percent (Eagan 1998). The upper control limit for the daily shift output performance rate of labour, as a function of the mean, process range and the standard deviation of the measured data obtained from Figure 4- 10, is 118 percent and the lower control limit is 3 percent (see Figure 5- 12). Realistically this is not viable, thus the upper specification limit is lowered to 90 percent which is the maximum output performance rate expected on a Wednesday afternoon shift. Consequently, the same rate is applied to the lower specification limit which is set at 30 percent. Likewise, any data point falling outside the lower specification limit is considered to be a common cause variation.
Figure 5- 13 shows the upper and lower control limits for the daily output performance rate of labour. Once again, the upper control limit is realistically a non viable target thus the upper specification limit is lowered to 75 percent which is the

maximum output performance rate expected on Wednesdays and Thursdays. Consequently, the same rate applies to the lower specification limit which is set at 45 percent.

The discussion has only addressed a single-step process. For multi-step processes, each step will have its associated sigma quality level. In addition, having multi-step processes makes it rather difficult to achieve a six sigma quality level. Therefore, not all contractors should consider this as the appropriate level. Rather the appropriate sigma quality level should be based on the strategic importance of the process and the cost to benefit ratio expected (Linderman et al 2003, Breyfolge 2003).

The statistical control chart provides an indication showing how the work is progressing but it does not provide a solution for solving the main problem that is causing performance variation. At Toyota, it is said that problem solving is 20 percent statistical tools and 80 percent thinking (Liker 2004). Unfortunately, some companies get caught up in using sophisticated analysis tools, *"where problem solving seems to be 80 percent tools and 20 percent thinking"* (Liker 2004).

The six sigma quality approach is not perfect but it does not place the same supremacy TQM placed on quality at the expense of all other business aspects (Harry and Schroeder 2000, Pande et al 2000, Breyfolge 2003).

5.2.1 Six Sigma and Lean Construction

Users of six-sigma must select metrics against which progress and improvements can be assessed (Abdelhamid 2003). For example, the rolled throughput yield is the most common metric used by organisations to facilitate comparisons and benchmarking. The yield represents the percentage of units that pass final inspection relative to the number of units that were processed and the rolled throughput yield is the product of the yield of each process or sub-process required to produce a unit or a service (Breyfolge 2003). The yield metric can hide performance variation and the aim of lean is to expose and eliminate the hidden factors that are causing variation, *''this is facilitated in six sigma projects through the use of rolled throughput yield''* (Abdelhamid 2003).

The last planner system is a good example for a lean approach to construction management. It uses percent plan complete (PPC) as a metric to measure the quality of the commitments made and the reliability of workflow. PPC is the number of completed assignments expressed as a ratio of the total number of assignments made in a given week. This metric is usually reported for a particular trade or crew on a daily or weekly basis. Table 4- 23 shows PPC data collected for a tile fixing job on the ISVR building construction site during the month of August 2006. The average weekly PPC for the crew in Table 4- 23 is 65%.

The average PPC reported for the single process of placing the tiles to the external rails of the ISVR building can be converted to a sigma quality level as follows:

$MAPPnorm = -\ln(PPCnorm)$ 1

Using $PPC = 0.65$ in equation 1 above gives a

$MAPP = -\ln(PPC) = -\ln(0.65) = 0.4308$

Where *MAPP* stands for missed assignments per plan (Abdelhamid 2003).

The standard normal table shows that $ZMAPP = 0.17$, hence, 2

$Zbenchmark = ZMAPPnorm + 1.5 = 0.17 + 1.5 = 1.67$

Where $ZMAPPnorm$ is the standard normal value corresponding to the $MAPPnorm$, found using Equation 1 (Abdelhamid 2003).

$PPM = e^{\left[\left(29.37-(SigmaQualityLevel-0.8406)^2\right)/2.221\right]}$ 3

Where PPM is the rate in parts per million (Abdelhamid 2003).

Hence, the tile installation process is operating at a 1.67 sigma quality level that is equivalent to a PPM rate of 405,975.

The principle benefit of finding the sigma quality level is to give a better sense of the magnitude of the process performance failure. In other words, reporting that the process is 35% off-target is not the same as stating that the process is operating with a defect rate of 405,975 PPM.

Six-sigma is considered an effective tool for problems that are *''hard to find but easy to fix''* and lean tools are effective for *''easy to find but hard to fix''* problems (Hammer and Goding 2001). The combination of lean with six-sigma provides a strong framework for the identification and elimination of the hidden factors that are causing variation. Where lean creates the standard, six-sigma identifies and eliminates the causes of variation (Breyfolge et al 2001).

5.2.2 Causes of Labour Inefficiency and Workforce Management Practices

The labour output performance variation survey shows that Monday is the most inefficient working day of the week and that Wednesday in addition to Thursday are the most efficient working days of the week. It suggested that the subcontracting environment is the reason for the lower labour efficiency level expected on a Monday, because subcontracting companies move labour around different sites. This may be because subcontractors pack up tools on Friday afternoons on one site ready to locate on a new site on Monday.

The survey also acknowledged the main causes of labour inefficiency related to poor material management, ineffective utilisation of resources and incorrect communication. In addition, rework and adverse weather conditions were reported in the tile fixing job on the ISVR building construction site during the month of August 2006 as shown in Table 4- 23, causing the process to be 35% off-target.

Labour inefficiencies have also been shown to be very expensive as articles and reports have been published describing the effects of scheduled overtime (Thomas and Raynar 1997), poor material management and vendor relations (Thomas and Sanvido 2000), construction changes (Thomas and Napolitan 1995; Hanna et al 1999a; Hanna et al 1999b), disruptions (Thomas and smith 1990; Thomas and Oloufa 1995; Horner and Talhouni 1993), and wasteful workforce management practices (Thomas et al 2003). The workforce management deficiencies identified by Thomas et al (2003) included insufficient work to perform, over staffing and ineffective use of work teams. These deficiencies have been shown to impact labour productivity negatively (Thomas and Horman 2006). In fact, Thomas et al (2003) consider overstaffing as the most significant cause of loss of labour efficiency.

For example, labour inefficiency related to overstaffing was identified by Thomas and Horman (2006) in the daily productivity measurement of a structural steel erection activity. At the beginning of the activity work was delayed by adverse weather, but from workday 18 to workday 21, after the erection of steel pieces had been finished, the crew was overstaffed by about a third. Four of the worst productivity performance days occurred when the crew was overstaffed. Overstaffing is known to be the cause because on workday 22 the crew size was reduced and the productivity improved. Thomas and Horman (2006) proposed some basic workforce management principles to avoid loss of labour efficiency, for example:

- Contractors should staff an activity with labour resources consistent with the amount of work available to be performed with respect to variability in the project.

- A contractor needs to have a good termination or layoff policy at the crew and project levels.

- In instances of uncontrollable variability, more labour than planned may need to be applied rapidly to complete work in the required time frame.

- Daily schedules should be planned to prolong the period of highest work activity.

With only the objection to the layoff policy at the crew and project levels, most of these workforce management principles provide positive guidelines for project managers to avoid labour inefficiency related problems. Ballard et al (2005) denounce the proposed layoff policy in citing the declaration of the international labour conference in 1944 that labour is not a commodity.

For a construction site where labour is provided by a subcontracting company that has adequate work demand at other construction sites, it is acceptable to invoke a flexible capacity strategy that switches labour among other sites. But for a construction site where labour is directly hired by the main contractor to carryout a specific job, a flexible layoff strategy should not be put into place. In such cases, the elevation of flexible capacity strategy to a primary principle is ethically not justifiable.

The key learning from the Toyota distribution and sales system to the construction industry is that the marketing and sales department of each subcontracting company is responsible for creating adequate market demand. This policy will ensure that labour can continue to carry out various job activities for project managers at different construction sites. Thus, it will help to avoid adverse effects on worker morale.

5.3 Site Material Management

The labour output performance variation survey shows that the highest number of mistakes is expected on a Monday. It is possible that this is due to a lack of familiarity with the site and the required task. It also shows that the most recurrent cause of labour inefficiency is possibly associated with material management. It has been observed, in general, that for all types of material management deficiencies, there is a reduction in daily productivity of about 40% (Thomas and Smith 1990).

Deficiencies include running out of materials, improper storage, double handling and others (Thomas et al 2005 b).

Site material management is defined as the allocation of delivery, storage, and the handling of spaces and resources to minimise labour inefficiency problems related to poor material management (Thomas et al 2005 b).

Developing an on-site material handling plan, in accordance with the site layout provided, is part of material management.

The published literature on developing a material handling plan based on site layout can be characterised as *"black box"* solutions (Thomas et al 2005 b).

Some involve the development of an extensive knowledge base (Zouein and Tommelein 1999), whereas others do not rely on an extensive knowledge base (Mawdesley et al 2002). All authors recognise the complexity of the site layout problem and generally agree that there are multiple selection criteria, multiple constraints and that the plan changes over time.

The most comprehensive algorithms use the selection criteria as the minimum travel distance or minimum transportation cost (Zouein and Tommelein 1999; Mawdesley et al 2002; Tam et al 2002). The algorithms concentrate on positioning facilities to satisfy the constraints while satisfying the objective. Thomas et al (2005 b) believes that applying multiple criteria such as the transportation costs and travelled distance to a small site is less important than the site layout itself.

This is because the site plan used at the beginning of a project may not be suitable for the succeeding part of the project. The on-site material handling calculation model is meant to serve as a lean tool pushing towards the *"workforce management strategies"* suggested by Thomas et al (2005 a).

The model can be characterised as a black box solution, because it is based on the transportation model taken from operation research. It uses the linear programming algorithm to balance supply to demand.

The model facilitates site material management and creates continuous material flow for labour, which should help to minimise labour inefficiencies related to disruptions. Furthermore, the proposed target group to use this model are the site managers. In order to make the model accessible and user friendly to them, the model is expressed mathematically in an Excel format.

The advantage of making the model available in an Excel format is that the mathematical equations can be made transparent for users to view.

Thomas et al (2005 b) in accordance with the algorithmic solution believes *"that a general heuristic approach might be more satisfactory in allowing the planner to adapt to the uniqueness of each site".*

The specific objective for the on-site material handling calculation model is the determination of a minimum-time travel plan for transporting a single commodity from a number of material storage locations, buffers, to a number of destinations within the construction site. This objective puts the lean supply principles into practice as a result of having to reduce the batch size of the material supplied for each load, increasing the frequency of material supply and reducing the required cycle time. This requires that the batch size for each load of material is optimised individually in respect to the available resources.

The model also requires the pre-identification of the storage locations and their storage capacities, the identification of the locations of demand and their demand for material, and the calculation of the cycle times between each buffer and each location of demand. These requirements provide the flexibility for the model to manage each material handling activity independently.

Thomas et al (2005 b) proposed some fundamental site material management principles. He recommended that the sequence of work should be integrated with the storage plan to maximise the utilisation of potential storage locations. Riley has written at length about the need to do so (Riley and Savindo 1995, 1997).

For example, during the application of the on-site material handling calculation model to the ISVR building construction site, the first floor was used to store the insulation material. This procedure helped to create more working space for workers and provided shelter for the insulation material from the adverse weather conditions outside the building.

The amount of material stored inside a building should not exceed the demand for 1 or 2 days of work. Comparable to lean supply, material should be delivered more frequently to the construction site in smaller batches.

Thomas showed the affects of delivery methods (Thomas and Sanvido 2000).

It was shown that the erection of structural steel directly from the delivery truck was the preferred way because it eliminated double handling of material.

Finally, it is important to ensure that the delivery rate from vendors is compatible with the installation rate in the field.

For example, during the application of the on-site material handling calculation model to the EEE building construction site, the vendor's delivery schedule for the panels was fixed and did not permit any changes (Figure C 4).

This restricted the pull principle from being placed into practice, because the external supply of panels was no longer determined by the internal supply chain.

Most of the proposed principles are comparable with lean construction, they share the same objective, but Thomas considers the baseline productivity to be the only measurement that is consistent internationally (see Figure F 1).

5.4 Real Time Performance Information System

Lamming (1993) recognised the importance of transparency in the exchange of information between suppliers and believes that the planning of capacity and the operational communication must be undertaken jointly for lean supply to be effective.

Nakagawa (2006) developed a real time performance information system using a mobile telephone device, to eliminate the obstacle related to the fact that information is often not in real time, imprecise and not shared with the foremen, site workers and head offices of both the contractor and subcontractors.

Nakagawa (2004, 2006) believes that the explicit sharing of information between workers, foremen, site engineers, project engineers and vendors is essential for work to be implemented efficiently

Some of the critical information at the worksite is the amount of work completed compared to the planned amount, as well as the reason why the planned amount was not completed (Nakagawa 2006).

An understanding of the information will enable foremen, site engineers and project managers to work together to implement improvements that will make construction lean.

Nakagawa (2006) explains that in Japan, site engineers talk with foremen regarding how to improve the material, machinery and manpower processes on a daily basis. They use data obtained from that same day to try to put lean construction into practice. But usually, the data is verbal and not precise. In order to obtain precise data quickly, it is important to develop real time performance information systems using mobile communications (Garza and Howitt 1998; Nakagawa 2006). This system is being developed in which Personal Digital Assistants (PDA's), hand terminal and bar codes are used to quickly share information at the worksite (Lin 2004; Olofsson and

Emborg 2004; Nakagawa 2006). A Lean Enterprise Web-based Information System for construction is being developed using PDA's and it facilitates the view of PPC on the PC (Sriprasert and Dawood 2003; Nakagawa 2006).

Nakagawa (2006) recommend the usage of mobile phones instead of PDA's as an information terminal for the construction work information system. Simply because, a mobile phone is smaller in size and almost every foreman normally carries a notebook and mobile phone, making it unnecessary to purchase or lease a mobile phone.

Nakagawa (2006) explains how the construction work data transmitted by the foreman is entered to the database that matches the sites keyword and foreman's keyword on the server at the contractor's site office and head offices of the contractor and subcontractor. It is also possible to issue a request from the foreman's mobile phone to output the records in the database to the foreman's mobile phone. The server can also be accessed by PC from the contractor's site office and the head offices of the contractor and subcontractor. In addition, the data in the database can be converted into Excel format data then processed for further statistical analysis of the construction work data.

The real time update on the situation of a construction site to foremen, site engineers, project managers and vendors, also helps to make the delivery rate from vendors compatible with the installation rate of workers in the field. This is mainly helpful during unforeseen incidents such as equipment breakdown, which cause delays in schedule and lead to excessive material storage on the construction site.

For example, as the panel installation activity was carried out at the EEE building construction site during the month of February 2006, a delay of four days occurred because of the unpredicted breakdown of the tower crane.

As a result, the senior site engineer increased the cycle time for the on-site handling activity of the scheduled panels for March 2006, to buffer any unexpected delays as seen in Table 4- 12.

The change of information related to the reduced rate of workers, was only exchanged with the project engineer on an operational level but not with the vendor. This is why the external supply chain was not controlled by the internal supply chain any longer. Consequently, the vendor's delivery rate was faster than the workers installation rate and more material than actually needed was stored on site.

5.5 Labour Productivity

The First World War introduced high throughput homicide and other industrial methods into warfare (Ellis 1975). Following the war more academic researchers and industrialists started to research the factors that are affecting labour productivity. Vernon (1921) drew attention to the effect of physical fatigue upon the performance of factory workers as he observed a 13 % increase in the total performance output of munitions workers, although the working hours were reduced from 75 to 55 hours per week.

Construction workers are exposed to a higher level of physical fatigue than factory workers, because the work processes in construction are less automated than in manufacturing. Mayo (1933) identified the causes of fatigue and found that monotony was high among the workers.

5.5.1 Monotony

Monotony and fatigue are two words which are used to *"denote any sort of induced inbalance in the worker such that he cannot continue work, or can continue only at a lower level of activity"* (Mayo 1933). Mental preoccupations, pessimism and rage induced in the workers by the condition of their work are some factors causing such unbalance.

For example, it was observed that monotonous job activities had a negative impact on the performance of workers, carrying out the tile fixing job on the ISVR building construction site during the month of August 2006. Table 4- 23 shows that among the 7 wasted working days, 2 days were wasted because the workers did not carry out any tile installation and handling activities.

Mayo (1933) has noticed from his experiments that the introduction of rest periods had a positive impact on labour productivity. He also noticed that following this Monday and Friday were no longer the worst days in the week for productivity.

For example, high productivity outputs were recorded on two Fridays as the tile fixing job on the ISVR building construction site was carried out.

The labour output performance variation survey shows that Monday is the most inefficient working day of the week followed by Friday, as shown in Figure 4- 5 and Figure 4- 8. It is possible that with the introduction of more frequent rest pauses, productivity in construction could be improved just as demonstrated by Mayo (1933) seven decades ago.

5.5.2 The Hawthorne Effect

Hawthorne is the name of a factory where the effect was first thought to be observed and described namely in the Hawthorne works of the Western Electric Company in Chicago, 1924-1933.

Gale (2004) explained that the factory's suppliers claimed that *"better lightning improved productivity"*. Based on their belief, the famous illumination experiments were carried out at the factory.

The study was carried out in the relay assembly test room. A relay was a switching device activated in the telephone exchange as each number was dialled.

Six experienced workers were moved into the area constructed for the illumination experiments in April 1927, five to work on assembly and the sixth to keep them supplied with parts.

The aim was to examine the effect of change in working arrangements upon productivity. Pennock and Stoll were the engineers who carried out the illumination experiments at the factory. They treated the relay workers like an engine in its test bed, altering the conditions to achieve maximum output. Output did indeed increase in response to shorter hours and the introduction of rest breaks, but Pennock was confused because he could not find a logical explanation for the increase in productivity in adverse lighting conditions. Most confusing of all, was that the relay workers increased the number of relays they were making from 2400 relays per week, to 2900 relays per week in adverse lightening conditions, but only made 100 more relays, 3000 relays per week instead of 2900 when the most successful innovations were subsequently reintroduced. The company became interested and brought in Elton Mayo, who was an Australian academic consultant at the Harvard Business School, to study the reason that caused productivity to increase.

He observed that the relay workers were more effective *"when relieved of the apprehension of authority"* (Gale 2004).

Pennock addressed the personnel research federation in New York on the 15th of November 1929, describing the test room and claimed that the relay workers:

> ''Say they have no sensation of working faster now than under the previous conditions... they have a feeling that their increased production is in some way related to the distinctly freer, happier and more pleasant working environment'' (Mayo 1933).

As a result of the observation, rest breaks were introduced across the factory with a general increase in productivity (Gale 2004). The observation of production shows

that workers under observation perform differently from workers working independently.
Table 4- 27 shows PPC data collected for a tile fixing job on the ISVR building construction site during the month of September 2006. The average weekly PPC for the crew in Table 4- 27 is 100%. This is an exceptionally good output rate for construction workers, but normally such a rate is not expected, particularly, knowing that labour in construction is exposed to a higher level of physical fatigue which causes labour performance inefficiencies.
Therefore, this high output performance rate could be either interpreted as a positive indication for a continuous learning curve amongst the crew members at the ISVR building construction site, or, it could be interpreted that the workers felt that their performance was being watched. Consequently, productivity was higher than expected.
The Hawthorne effect raises the awareness for the empowerment of workers on an operational level and provides a soft system approach to construction management.
It is important to establish trust between workers, foremen, site engineers and project managers. Effective communication between site engineers and foremen on a frequent basis increases the level of responsibility among all crew members. In addition, it provides site engineers and project managers with sufficient insight needed to take better corrective actions on the site.

5.6 Resistance to Change and Empowerment

The application of the on-site material handling calculation model to the EEE building construction site, provides evidence for good communication practices between the researcher, senior site manager and the construction crew members. As the model helped the senior site manager to monitor and structure the flow of material, he was keen on implementing the model to other type of materials on the site. Unfortunately, the senior project manager refused to collaborate further and asked for the field work to stop (see Figure C 5). This is a typical example for increased management control and managers resistance to change.
Green (1999) criticised the proponents of lean production (Wickens 1987; Womack and Jones 2003) for being one sided in their view towards lean and that they neglect the fact that lean exerts increased management control and reduces workers autonomy (Garraham and Stewart 1992). Alvesson and Willmott (1996) believe that TQM and

JIT are imbalanced practices, because TQM places all the efforts on quality at the expense of other aspects such as safety, stress of work and loss of individual freedom. Fucini and Fucini (1990) investigated the implementation of lean production in Mazda's plant in Michigan, USA. They have provided evidence that the Japanese are able to adapt lean production to a Western environment, but they also point to the gradual disappointment of the American workforce. Despite the relatively high wages available, workers were found to express frequent concerns regarding safety, stress of work, loss of individual freedom and biased employment practices. The same concerns were also found at the Nissan plant in Sunderland, UK, which was held up by the Egan report as a perfect example of good practice (Green 1999).

Beale (1994) further describes how the Nissan system of continuous improvement depends on a single union agreement. Such an agreement does not allow workers to retaliate against managerial decisions and assures that the negotiation power remains firmly with Nissan's management. Nissan's initial location at Sunderland was conditional on accepting a single union agreement (Green 1999).

Garrahan and Stewart (1992) argue that Nissans supposed regime of flexibility, quality and teamwork translates in practice to one of control, exploitation and surveillance.

Womack and Jones (2003) have shown how lean production helped the managers at the Toyota plant to introduce changes to the manufacturing processes, which improved productivity and reduced the work pace of labour. These changes were not imposed by the management, but they involved the participation of the front line operational plant workers. As a matter of fact, Spear and Bowen (1999) have clearly identified the four rules for implementing lean production, which are:

- Ensure that all the various activities of work are highly specified to content, sequence, timing, and outcome.
- Ensure that every customer-supplier connection is direct.
- Ensure that the pathway for every product and service is simple and direct.
- Ensure that any improvement is made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organisation.

Furthermore, they have shown that when Toyota enhances a process, it breaks the process down into smaller detailed steps using the insight of their operational workers. Lean production might be demanding, but it does not ignore the human element. It is possible that in a Western environment lean is carried out differently from how it is actually intended to be implemented.

For example, when the Toyota sales representatives misjudged the actual market demand for new car sales in 1950, Toyota's President Kiichiro Toyoda at that time, took the responsibility for the over optimistic sales forecast of cars and resigned. Although Kiichiro Toyoda was a family member of the founders of the Toyota Motor Corporation, he decided to resign for a mistake that was made by the management. If the same mistake would have happened in a Western environment, the management would have blamed the workers and stayed in power. Not only that, but they would have started to downsize their workforce to save money at the expense of the workforce.

Green (1999) also mentioned that it is unfair to single out Japanese car manufacturers for their exploitative employment practices, because the harsh global market conditions mean that Western corporations are obliged to follow similar trends. According to Grieder (1997), the business objective of multi-national corporations is driven by global politics. *"Japanese, American and European car manufactures all find it increasingly attractive to transfer production to low-wage economies which have fewer checks against the excesses of capitalism"* (Green 1999).

The same threat applies to the construction industry, as immigrant worker from Eastern Europe are willing to work for lower wages. Some construction companies might be tempted to take the risk of recruiting lower skilled workers to save money at the expense of workforce safety. But it is unfair to associate such an issue with lean practices, because this should be the concern of the officials responsible for the governing legislations in each country.

5.7 Summary

It is important to understand the difference between common and special cause variation prior to attempt to address quality problems. The optimum value for a control chart is represented around the mean value and it can shift up to ± 1.5sigma. The sigma quality level for the tile installation process was calculated at, 1.67sigma and the principle benefit of finding the sigma quality level is to give a better sense of the magnitude of the process performance failure. In other words, reporting that the process is 35% off-target is not the same as stating that the process is operating with a defect rate of 405,975 PPM. It has been found that the main cause of labour inefficiency is related to labour flow disruptions such as overstaffing, but flexible labour termination policies should not be put into practice, because labour should not be considered as a commodity. It also has been found that material management deficiencies reduce daily productivity and developing an on-site material handling plan, in accordance with the site layout provided, is part of material management. The storing of the insulation material inside the ISVR building helped to create more working space for workers and provided shelter for the insulation material from the adverse weather conditions outside the building.

The real time update on the situation of a construction site to foremen, site engineers, project managers and vendors, helps to make the delivery rate from vendors compatible with the installation rate of workers in the field. It has been found that the information related to the reduced rate of workers at the EEE building construction site, was not communicated to the vendor. This is why the vendor's delivery rate was faster than the workers installation rate and more material than actually needed was stored on site. It has been found that monotonous job activities have a negative impact on labour productivity, but with the introduction of more frequent rest breaks, it is possible to improve productivity in construction just as demonstrated seven decades ago. A possible interpretation for the high output performance rate, recorded at the ISVR building construction site, is that the workers felt that their performance was being watched. Consequently, productivity was higher than expected. The Hawthorne effect raises the awareness for the empowerment of workers on an operational level and provides a soft system approach to construction management. It has been noticed that the on-site material handling calculation model, helped the senior site manager at the EEE building construction site to monitor and structure the flow of material. Although he was keen on further implementations for other type of materials on the site, the senior project manager refused to collaborate further and asked for the field work to stop. This provided a typical example for increased management control and managers resistance to change. It is very difficult to predict labour productivity in construction, because the processes in construction are less automated compared to manufacturing and construction workers are exposed to a higher level of physical fatigue. The on-site material handling calculation model puts the main lean concept mathematically into practice, as it projects the work load per person and identifies the specific batch size for each load, but does not predict factors that cause production irregularities. Factors such as monotony and physical fatigue are intangible and have a negative effect on productivity. Therefore, such factors should be integrated into the work schedules of construction workers.

Chapter Six Conclusions and Recommendations

6.1 Conclusions

The lean construction researchers are mainly classified into two different schools of thought. In addition, there are also some independent researchers such as Green who heavily criticised lean for increasing management control.

The first school of thought is led by researches such as Ballard, Howell and Koskella, who are members of the International Group for Lean Construction.

They believe that the reduction of the levels of workflow variability reduces the overall performance variability. They contradict themselves in proposing to eliminate the levels of workflow variability, yet on the other hand admit that variability is an unavoidable factor which can only be reduced but not eliminated.

They also neglect the fact that Toyota, which is the main contributor to lean, recommend to reduce the material buffers between the different processes and not to eliminate them.

The second school of thought is led by researchers such as Thomas, who does not consider himself a proponent of lean and believes that the development of flexible capacity management practices would help to reduce the overall performance variability. Although this school of thought does not believe in lean construction, their proposed workforce management principles and site material management principles have a lot in common with the lean concepts. Ballard recommends structuring the flow of material on an operational level and Thomas proposed to develop flexible capacity management practices, which also structures the flow of labour and the associated flow of material. Both ideas implement the lean concepts. They create flow, pull material through the different processes and add value to the processes at the operational level. The debate over labour performance variability provided the evidence that labour performance variation is unavoidable. It suggested that performance can be improved by placing emphasis on developing flexible capacity management practices instead of reducing levels of workflow variability. It also placed emphasis on developing on-site planning at an operational level, to ensure that all the various activities of work are highly specified in content, sequence, timing, and outcome. The objectives of this research were:

- First: to study the impact of lean techniques on the capacity management of the work processes of construction teams when viewed as a component of flow.
- Second: to provide a methodology for identifying the buffer locations and their capacities for storing materials at the construction site in collaboration with the workers involved.
- Third: to provide a methodology for identifying the locations of supply and to determine the demand of material for each of the selected locations in collaboration with the construction workers.
- Fourth: to reduce the overall level of variation by managing the daily labour performance output variation within a working weeks perspective.

The first objective was achieved by carrying out the trials of the on-site material handling calculation model on the EEE building project, the observation of the actual work performance and by considering the findings from the survey in the scheduling process for the trials that were carried out on the ISVR building project as a check-run of the model.

The second objective was achieved as an input requirement of the on-site material handling calculation model, involving the construction crew in the identification of the buffer locations and storage capacities. The involvement of the construction crew in the identification of the buffer locations and storage capacities at the ISVR building construction site has shown to be positive. They have managed to reduce the number of the buffer locations to one.

The third objective was achieved as an input requirement of the on-site material handling calculation model, involving the construction crew in the identification of the locations of supply and the material demand at each of the selected locations.

The fourth objective was achieved by considering the daily output performance variation weights, which were obtained from the survey, in the actual performance at the ISVR building construction site. In addition, maintaining a daily record of the actual performance, scheduling and reviewing the output of the actual work more frequently over shorter time periods contributed to reducing unexpected variation. Overall this research contributed to lean capacity management by developing the on-site material handling calculation model, to enhance the workload predictability at the operational level, assist site engineers to structure the flow of material which is closely associated with the flow of labour and monitor labour performance.

It has been shown that the on-site planning at the operational level increases the workload predictability and that less labour is needed when planning reliability is increased. The lean concepts of creating flow, pulling the material through the processes and synchronising the resources with respect to the actual available work, provided the basis for the idea of developing an on-site material handling calculation model, which would put the lean concepts into practice. The on-site material handling calculation model was developed on the basis of the theory of constraints and it can be characterised as a black box solution, because it is based on the transportation model taken from operation research. It uses the linear programming algorithm to balance supply to demand. Furthermore, the proposed target group to use this model are the site managers and engineers. In order to make the model accessible and user friendly to them, the model is expressed mathematically in an Excel format. The advantage of making the model available in an Excel format is that the mathematical equations can be made transparent for users to view.

The specific objective for the on-site material handling calculation model was to determine a minimum-time travel plan for transporting a single commodity from a number of material storage locations, buffers, to a number of destinations within the construction site. This objective placed the lean supply principles into practice as a result of reducing the batch size of the supplied material for each load, increasing the frequency of material supply and reducing the required cycle time. The model also required the pre-identification of the storage locations and their storage capacities, the identification of the locations of demand and their demand for material, and the calculation of the cycle times between each buffer and each location of demand. These requirements provided the flexibility for the model to manage each material handling activity independently. The on-site material handling calculation model was utilised at the EEE building construction site and at the ISVR building construction site in a systematic method.

It was clear that the construction crew members understood the lean philosophy and the positive impact of lean to construction became recognised by them.

Just like in action research, promoting change in the researched subject, lean aims to focus on the production systems, involve downstream players in upstream decisions, carry out activities at the last responsible moment, generate systematic efforts to reduce supply-chain lead times and incorporate learning into project supply-chain management.

These aims were achieved by going into the actual workplace at the EEE building construction site, looking at the actual process, observing what was actually happening and collecting actual data.

In some cases it was shown that the actual work performance, compared to the projected scheduled workloads was not completely met by the workers. This has proven that labour performance variation is an inevitable factor for which the expected targeted scheduled activities should be synchronised. Therefore, a pilot survey was carried out whilst the application of the on-site material handling calculation model to the EEE building construction site was ongoing. This was followed by a full survey to identify and quantify the level of variation in daily output performance. The identified weights function as a buffer and absorb the daily variation output performance rate. It was found that the Wednesday afternoon shift has the highest expected output performance rate for completing targeted and scheduled work activities with a rate of 90 percent. Since the Wednesday afternoon shift has the highest expected output performance rate, it is recommended that new activities or activities that require a learning curve should be carried out on the Wednesday afternoon shift. It also was found that the overall average expected output performance rate for the entire week equals 60 percent. In addition, Monday in general is the most inefficient working day of the week and this is contrary to popular belief which suggests this is Friday.

The real time update on the situation of a construction site to foremen, site engineers, project managers and vendors, helps to make the delivery rate from vendors compatible with the installation rate of workers in the field. It has been found that the information related to the reduced rate of workers at the EEE building construction site, was not communicated to the vendor. This is why the vendor's delivery rate was faster than the workers installation rate and more material than actually needed was stored on site.

The labour output performance variation survey suggested that the subcontracting environment is the reason for the lower labour efficiency level expected on a Monday, because subcontracting companies move labour around different sites. This may be because subcontractors pack up tools on Friday afternoons on one site ready to locate on a new site on Monday.

The survey also acknowledged the main causes of labour inefficiency related to poor material management, ineffective utilisation of resources and incorrect communication. Further more, the labour output performance variation survey shows that the highest number of mistakes is expected on a Monday. It is possible that this is due to a lack of familiarity with the site and the required task. It also shows that the most recurrent cause of labour inefficiency is possibly associated with material management.

It has been found that the main cause of labour inefficiency is related to labour flow disruptions such as overstaffing, but flexible labour termination policies should not be put into practice, because labour should not be considered as a commodity. It also has been found that material management deficiencies reduce daily productivity and developing an on-site material handling plan, in accordance with the site layout provided, is part of material management.

It has been found that monotonous job activities have a negative impact on labour productivity, but with the introduction of more frequent rest pauses, it is possible to improve productivity in construction.

After the survey was analysed, the on site material handling calculation model was applied to the ISVR building construction site as a check-run.

It has been observed that the construction crew members at the ISVR building construction site, worked closely together with the site engineer in identifying the storage areas and storage capacities, areas of material demand and the quantities of material demand as well as improving the material handling techniques on the site as a team, communicating bilaterally allowing for feedback and feed-forward to take place effectively. This does not only provide a good example for communication, but it also shows the clear understanding of lean construction amongst the construction crew members. The storing of the insulation material inside the ISVR building helped to create more working space for workers and provided shelter for the insulation material from the adverse weather conditions outside the building.

A possible interpretation for the high output performance rate, recorded at the ISVR building construction site, is that the workers felt that their performance was being watched. Consequently, productivity was higher than expected. The Hawthorne effect raises the awareness for the empowerment of workers on an operational level and provides a soft system approach to construction management. It is very difficult to predict labour productivity in construction, because the processes in construction are less automated compared to manufacturing and construction workers are exposed to a higher level of physical fatigue. The on-site material handling calculation model puts the main lean concept mathematically into practice, as it projects the work load per person and identifies the specific batch size for each load, but does not predict factors that cause production irregularities. Factors such as monotony and physical fatigue are intangible and have a negative effect on productivity. Therefore, such factors should be integrated into the work schedules of construction workers.

6.2 Recommendations

The application of the on-site material handling calculation model to the EEE building project has shown that the scheduled work in some cases, was not completely achieved as projected by the model. As a result, a survey was carried out for the identification of the performance variation levels that could be incorporated into the on-site material handling scheduling process for reduction. The objective of the survey was to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variations. These daily variation weights should be incorporated into the on-site material handling scheduling process by anticipating a lower output rate compared to scheduled work. Thus, project managers plan for the best and expect the worst.

In addition, the application of the on-site material handling calculation model to the EEE building construction site and the ISVR building construction site, has shown that it is better to measure, average out and then assign the cycle time required for each batch of material to be transported from its storage area to its designated location of demand and then fitted in its physical position by the construction crew. Whenever the cycle time is measured and not determined by the site engineer, based on his personal experience, the workload predictability at the operational level is improved.

Factors such as monotony and physical fatigue are intangible and have a negative effect on productivity, but they can be reduced if the manual handling regulations are properly considered.

If a task involves heavy stress on a muscle group, it should be made as short as possible or the material load should be reduced.

In addition, if a task involves static loading of a muscle group, the effort time should be reduced by changing posture. Furthermore, high frequency and high effort tasks should be avoided. Moreover, moderate or high efforts that are sustained for 10 to 15 seconds before relaxation should be avoided unless they are done less than once in 5 minutes.

It is important to consider statistical performance measurement technique's within the perspective of human factors engineering, to help in identifying the root causes of variation and to give a better sense of the magnitude of the process performance failure. Thus, the appropriate sigma quality level should be based on the strategic importance of the process and the cost to benefit ratio expected.

The workforce management principles provide positive guidelines for project managers to avoid labour inefficiency related problems. This is why contractors should staff an activity with labour resources consistent with the amount of work available to be performed with respect to variability in the project. In instances of uncontrollable variability, more labour than planned may need to be applied rapidly to complete work in the required time frame, but flexible labour termination policies should not be put into practice, because labour should not be considered as a commodity. For a construction site where labour is provided by a subcontracting company that has adequate work demand at other construction sites, it is acceptable to invoke a flexible capacity strategy that switches labour among other sites.

On the other hand, for a construction site where labour is directly hired by the main contractor to carry out a specific job, a flexible layoff strategy should not be put into place. Thus, the marketing and sales department of each subcontracting company should be held responsible for creating adequate market demand.

Since the Wednesday afternoon shift has the highest expected output performance rate, it is recommended that new activities or activities that require a learning curve should be carried out on the Wednesday afternoon shift. In addition, since Monday is the most inefficient working day of the week, it could be considered as a makeup day.

The site material management principles help to avoid poor material handling practices. These principles recommend that the sequence of work should be integrated with the storage plan to maximise the utilisation of potential storage locations. This procedure helps to create more working space for workers and provides shelter for the building material from adverse weather conditions. Furthermore, the amount of material stored inside a building should not exceed the supply of 1 or 2 days. Comparable to lean supply, material should be delivered more frequently to the construction site in smaller batches. In addition, the erection of structural steel directly from the delivery truck eliminates the double handling of material. Moreover, it is important to ensure that the delivery rate from vendors is compatible with the installation rate in the field. It is important to establish trust between workers, foremen, site engineers and project managers. Effective communication between site engineers and foremen on a frequent basis increases the level of responsibility among all crew members. It also provides site engineers and project managers with sufficient insight needed to take better corrective actions on the site.

6.3 Future Work

The on-site material handling calculation model enhances the workload predictability at the operational level, assist site engineers to observe labour productivity and structure the flow of material which is closely associated with the flow of labour. It predicts the required work load per person and identifies the specific batch size for each load, but does not predict factors that cause production irregularities. Factors such as monotony and physical fatigue are intangible and have a negative effect on productivity. Therefore, such factors should be integrated into the work schedules. This requires prompt and precise data update of the produced on-site material handling schedules. In order to obtain precise data quickly, feedback, it is important to develop real time performance information systems using mobile communications. This system would help to provide revised, feed-forward schedules, to construction workers more frequently on a daily basis. The explicit sharing of information between workers, foremen, site engineers, project engineers and vendors is essential for work to be implemented efficiently. Some of the critical information at the worksite is the amount of work completed compared to the planned amount, as well as the reason why the planned amount was not completed. In addition to mobile communications, a Global Positioning System (GPS) device is useful to record the actual movements of

all construction workers on the construction site. This would assist in the identification of the root causes for the poor material handling practices. Each construction worker would have to be equipped with a GPS and mobile device.
The central system would record the GPS signals of the actual movements received from each construction worker, then the updated information, would be sent out to the mobile phones of each individual construction worker. This process would provide each worker individually, with the actual performance information, compared to the scheduled work. Each worker would know the remaining amount of work to be carried out and quantity of material loads to be completed. Some researchers might criticise this approach for creating a surveillance system, but an interactive understanding of the information will enable foremen, site engineers and project managers to work together to improve the material, machinery and manpower processes on a daily basis. Because the processes in construction are less automated compared to manufacturing and construction workers are exposed to a higher level of physical fatigue, it is important to introduce frequent rest pauses. Since the GPS devices record the actual movements of each construction worker individually, the actual performance information, received from the construction workers at each construction site, would help to identify appropriate rest brakes more realistically. It would also help to identify non added value movements which could be reduced and rearranged more efficiently.

6.4 Overall Conclusions

The on-site material handling calculation model helped the site engineers to structure the flow of work. This was achieved through the models computation of the required number of material loads and the batch size of each load, providing continuous supply of material. In addition, it provided a methodology for the identification of the buffer and demand destinations in collaboration with the workers involved.
This was achieved by going into the actual workplace at the EEE building construction site, looking at the actual process, observing what was actually happening, involving downstream players in upstream decisions, collecting actual data and incorporating learning into the on-site material handling scheduling process.
This research has resulted in trials of a prototype tool for on-site material handling.
The trials have demonstrated that the application of the tool can improve work scheduling and manage variability with an overall reduction in cost and time.

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Appendix A: Tables and Figures of Chapter Three

Data input sheet least cost method

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of(Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 3: Feed the locations of demand in respect to each method.

Step 1: Allocate the material demand and storing capacity.

LEAST COST METHOD:

From	**To Location**					**Capacity**
	A	B	C	D	E	
Buffer 1		100	200			300
Buffer 2	100	50		300	100	550
Buffer 3						0
Demand	100	150	200	300	100	850

Step 2: Allocate the cycle times in minutes.

From	**To Location**				
	A	B	C	D	E
	Transportation Time/ load of Units (1 load = X Units)				
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6
Buffer 3	0	0	0	0	0

From	**To Location**					**Total Required Hours**
	A	B	C	D	E	
Buffer 1	0.00	0.17	0.20	0.00	0.00	0
Buffer 2	0.27	0.12	0.00	1.20	0.20	2
Buffer 3	0.00	0.00	0.00	0.00	0.00	0
Total Required Hours	0	0	0	1	0	2

From	**To Location**					**Total Required Days**
	A	B	C	D	E	
Buffer 1	0.00	0.17	0.20	0.00	0.00	0.37
Buffer 2	0.27	0.12	0.00	1.20	0.20	1.78
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Days	0.27	0.28	0.20	1.20	0.20	2.15

From	**To Location**					**Total Required Weeks**
	A	B	C	D	E	
Buffer 1	0.00	0.17	0.20	0.00	0.00	0.37
Buffer 2	0.27	0.12	0.00	1.20	0.20	1.78
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Weeks	0.27	0.28	0.20	1.20	0.20	2.15

These are automated results used for computation purposes.

Table A 1: Data input sheet least cost method

Data input sheet North West corner method

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 4: Feed the locations of demand in respect to each method.

NORTH WEST CORNER:

From	To Location					Capacity
	A	B	C	D	E	
Buffer 1	100	150	50			300
Buffer 2			150	300	100	550
Buffer 3						0
Demand	100	150	200	300	100	850

From	To Location				
	A	B	C	D	E
	Transportation Time/ load of Units (1 load = X Units)				
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6
Buffer 3	0	0	0	0	0

These are automated results used for computation purposes.

From	To Location					Total Required Hours
	A	B	C	D	E	
Buffer 1	0.20	0.25	0.05	0.00	0.00	1
Buffer 2	0.00	0.00	0.20	1.20	0.20	2
Buffer 3	0.00	0.00	0.00	0.00	0.00	0
Total Required Hours	0	0	0	1	0	2

From	To Location					Total Required Days
	A	B	C	D	E	
Buffer 1	0.20	0.25	0.05	0.00	0.00	0.50
Buffer 2	0.00	0.00	0.20	1.20	0.20	1.60
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Days	0.20	0.25	0.25	1.20	0.20	2.10

From	To Location					Total Required Weeks
	A	B	C	D	E	
Buffer 1	0.20	0.25	0.05	0.00	0.00	0.50
Buffer 2	0.00	0.00	0.20	1.20	0.20	1.60
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Weeks	0.20	0.25	0.25	1.20	0.20	2.10

Table A 2: Data input sheet North West corner method

Data input sheet Vogel's approximation method

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of(Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 5: Feed the locations of demand in respect to each method.

These are automated results used for computation purposes.

VOGEL'S APPROXIMATION:

From	To Location					Capacity
	A	B	C	D	E	
Buffer 1				300		300
Buffer 2	100	150	200		100	550
Buffer 3						0
Demand	100	150	200	300	100	850

From	To Location				
	A	B	C	D	E
	Transportation Time/ load of Units (1 load = X Units)				
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6
Buffer 3	0	0	0	0	0

From	To Location					Total Required Hours
	A	B	C	D	E	
Buffer 1	0.00	0.00	0.00	0.70	0.00	1
Buffer 2	0.27	0.35	0.27	0.00	0.20	1
Buffer 3	0.00	0.00	0.00	0.00	0.00	0
Total Required Hours	0	0	0	1	0	2

From	To Location					Total Required Days
	A	B	C	D	E	
Buffer 1	0.00	0.00	0.00	0.70	0.00	0.70
Buffer 2	0.27	0.35	0.27	0.00	0.20	1.08
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Days	0.27	0.35	0.27	0.70	0.20	1.78

From	To Location					Total Required Weeks
	A	B	C	D	E	
Buffer 1	0.00	0.00	0.00	0.70	0.00	0.70
Buffer 2	0.27	0.35	0.27	0.00	0.20	1.08
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Weeks	0.27	0.35	0.27	0.70	0.20	1.78

Table A 3: Data input sheet Vogel's approximation method

Data input sheet longest required time method

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 6: Feed the locations of demand in respect to each method.

AD HOC METHOD:
Longest Required Time

From	To Location A	B	C	D	E	Capacity
Buffer 1			200		100	300
Buffer 2	100	150		300		550
Buffer 3						0
Demand	100	150	200	300	100	850

These are automated results used for computation purposes.

From	To Location A	B	C	D	E
	Transportation Time/ load of Units (1 load = X Units)				
Buffer 1	6	5	3	7	7
Buffer 2	8	7	4	12	6
Buffer 3	0	0	0	0	0

From	To Location A	B	C	D	E	Total Required Hours
Buffer 1	0.00	0.00	0.20	0.00	0.23	0
Buffer 2	0.27	0.35	0.00	1.20	0.00	2
Buffer 3	0.00	0.00	0.00	0.00	0.00	0
Total Required Hours	0	0	0	1	0	2

From	To Location A	B	C	D	E	Total Required Days
Buffer 1	0.00	0.00	0.20	0.00	0.23	0.43
Buffer 2	0.27	0.35	0.00	1.20	0.00	1.82
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Days	0.27	0.35	0.20	1.20	0.23	2.25

From	To Location A	B	C	D	E	Total Required Weeks
Buffer 1	0.00	0.00	0.20	0.00	0.23	0.43
Buffer 2	0.27	0.35	0.00	1.20	0.00	1.82
Buffer 3	0.00	0.00	0.00	0.00	0.00	0.00
Total Required Weeks	0.27	0.35	0.20	1.20	0.23	2.25

Table A 4: Data input sheet AD HOC method

Hourly number of loads calculation sheet
(Least cost and North West corner methods)

These are automated results used for computation purposes.

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

LEAST COST METHOD:

From	To Location Hourly Required Number of (Units x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	25	50	0	0	75
Buffer 2	25	13	0	75	25	138
Buffer 3	0	0	0	0	0	0
Supply	25	38	50	75	25	213

From	To Location Hourly Required Loads of (Unit x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	1	2	0	0	3
Buffer 2	1	1	0	3	1	6
Buffer 3	0	0	0	0	0	0
Supply	1	2	2	3	1	9

From	To Location Hourly Required Number of (Units x/1 Load) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	25	25	0	0	50
Buffer 2	25	13	0	25	25	88
Buffer 3	0	0	0	0	0	0
Supply	25	38	25	25	25	138

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

NORTH WEST CORNER:

From	To Location Hourly Required Number of (Units x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	25	38	13	0	0	76
Buffer 2	0	0	38	75	25	138
Buffer 3	0	0	0	0	0	0
Supply	25	38	51	75	25	214

From	To Location Hourly Required Loads of (Unit x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	1	2	1	0	0	4
Buffer 2	0	0	2	3	1	6
Buffer 3	0	0	0	0	0	0
Supply	1	2	3	3	1	10

From	To Location Hourly Required Number of (Units x/1 Load) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	25	19	13	0	0	57
Buffer 2	0	0	19	25	25	69
Buffer 3	0	0	0	0	0	0
Supply	25	19	32	25	25	126

Table A 5: Hourly number of loads calculation sheet 1 of 2

Hourly number of loads calculation sheet
(Vogel's approximation and AD HOC methods)

These are automated results used for computation purposes.

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location Hourly Required Number of (Units x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	0	75	0	75
Buffer 2	25	38	50	0	25	138
Buffer 3	0	0	0	0	0	0
Supply	25	38	50	75	25	213

From	To Location Hourly Required Loads of (Unit x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	0	3	0	3
Buffer 2	1	2	2	0	1	6
Buffer 3	0	0	0	0	0	0
Supply	1	2	2	3	1	9

From	To Location Hourly Required Number of (Units x/1Load) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	0	25	0	25
Buffer 2	25	19	25	0	25	94
Buffer 3	0	0	0	0	0	0
Supply	25	19	25	25	25	119

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

AD HOC METHOD:
Longest Required Time

From	To Location Hourly Required Number of (Units x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	50	0	25	75
Buffer 2	25	38	0	75	0	138
Buffer 3	0	0	0	0	0	0
Supply	25	38	50	75	25	213

From	To Location Hourly Required Loads of (Unit x) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	2	0	1	3
Buffer 2	1	2	0	3	0	6
Buffer 3	0	0	0	0	0	0
Supply	1	2	2	3	1	9

From	To Location Hourly Required Number of (Units x/1Load) in a Working Day by each Worker					Capacity
	A	B	C	D	E	
Buffer 1	0	0	25	0	25	50
Buffer 2	25	19	0	25	0	69
Buffer 3	0	0	0	0	0	0
Supply	25	19	25	25	25	119

Table A 6: Hourly number of loads calculation sheet 2 of 2

Least cost method produced schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

Step 7: Enter the values for the variable parameters and change them until the conditions are satisfied.

LEAST COST METHOD:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	0	2	4	0	0	6	
	Number of (Units x / 1 Load)	0	25	25	0	0	150	300
	Cycle Time/Load/Worker in Minutes	0	5	3	0	0	11	
Buffer 2	Number of Loads/Worker	2	2	0	6	2	12	
	Number of (Units x / 1 Load)	25	13	0	25	25	276	552
	Cycle Time/Load/Worker in Minutes	8	7	0	12	6	57	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	8	12	6	36	6	68	
	Required Time (Hours)	0.13	0.2	0.1	0.6	0.1	1	
No.of (Workers or Group of workers)	Supply	100	152	200	300	100		852
2	Difference (Supply & Demand)	0	2	0	0	0		2

Time duration:	
Weekly Working Hours	1
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	0%
Ahead of Schedule (% and £)	0%
Volume Rates:	
Number of Transported Units	852
Over Production Rate(%)	0.24%
Cost of Labour £	£20

These are the ready made schedules and output results for each method.

Table A 7: Least cost method produced schedule

North West corner method produced schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

NORTH WEST CORNER:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	2	4	2	0	0	8	
	Number of (Units x / 1 Load)	25	19	13	0	0	152	304
	Cycle Time/Load/Worker in Minutes	6	5	3	0	0	19	
Buffer 2	Number of Loads/Worker	0	0	4	6	2	12	
	Number of (Units x / 1 Load)	0	0	19	25	25	276	552
	Cycle Time/Load/Worker in Minutes	0	0	4	12	6	50	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	6	10	11	36	6	69	
	Required Time (Hours)	0.1	0.17	0.18	0.6	0.1	1	
No.of (Workers or Group of workers)	Supply	100	152	204	300	100		856
2	Difference (Supply & Demand)	0	2	4	0	0		6

Time duration:	
Weekly Working Hours	1
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	0%
Ahead of Schedule (% and £)	0%
Volume Rates:	
Number of Transported Units	856
Over Production Rate(%)	0.71%
Cost of Labour £	£20

These are the ready made schedules and output results for each method.

Table A 8: North West corner method produced schedule

Vogel's approximation method produced schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

VOGEL'S APPROXIMATION:

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	0	0	0	6	0	6	
	Number of (Units x / 1 Load)	0	0	0	25	0	150	300
	Cycle Time/Load/Worker in Minutes	0	0	0	7	0	21	
Buffer 2	Number of Loads/Worker	2	4	4	0	2	12	
	Number of (Units x / 1 Load)	25	19	25	0	25	276	552
	Cycle Time/Load/Worker in Minutes	8	7	4	0	6	36	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	8	14	8	21	6	57	
	Required Time (Hours)	0.13	0.23	0.13	0.35	0.1	1	
No.of (Workers or Group of workers)	Supply	100	152	200	300	100		852
2	Difference (Supply & Demand)	0	2	0	0	0		2

Time duration:	
Weekly Working Hours	1
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	0%
Ahead of Schedule (% and £)	0%
Volume Rates:	
Number of Transported Units	852
Over Production Rate(%)	0.24%
Cost of Labour £	£20

These are the ready made schedules and output results for each method.

Table A 9: Vogel's approximation method produced schedule

AD HOC method (longest required time) produced schedule

Prepared by: Eng.Basil Al-Sasi 2005

Variable Parameters:	
Working Days / Working Week	1
Working Hours / Working Day	1
Number of Units X / Load	25
No.of (Workers or Group of workers)	2
Payment/ Worker/ Hour	10
Fixed Parameters:	
Working Hours / Week	1
Number of Working Weeks	1

AD HOC METHOD:
Longest Required Time

From	To Location	A	B	C	D	E	Total	Total No. of Units
Buffer 1	Number of Loads/Worker	0	0	4	0	2	6	
	Number of (Units x / 1 Load)	0	0	25	0	25	150	300
	Cycle Time/Load/Worker in Minutes	0	0	3	0	7	13	
Buffer 2	Number of Loads/Worker	2	4	0	6	0	12	
	Number of (Units x / 1 Load)	25	19	0	25	0	276	552
	Cycle Time/Load/Worker in Minutes	8	7	0	12	0	58	
Buffer 3	Number of Loads/Worker	0	0	0	0	0	0	
	Number of (Units x / 1 Load)	0	0	0	0	0	0	0
	Cycle Time/Load/Worker in Minutes	0	0	0	0	0	0	
Over All Performance	Required Time (Minutes)	8	14	6	36	7	71	
	Required Time (Hours)	0.13	0.23	0.1	0.6	0.12	1	
No.of (Workers or Group of workers)	Supply	100	152	200	300	100		852
2	Difference (Supply & Demand)	0	2	0	0	0		2

Time duration:	
Weekly Working Hours	1
Working Days / Working Week	1.00
Number of Working Weeks	1.00
Behind schedule (% and £)	0%
Ahead of Schedule (% and £)	0%
Volune Rates:	
Number of Transported Units	852
Over Production Rate(%)	0.24%
Cost of Labour £	£20

These are the ready made schedules and output results for each method.

Table A 10: AD HOC method produced schedule

Demand supply chart (for locations A, B, C, D &E)

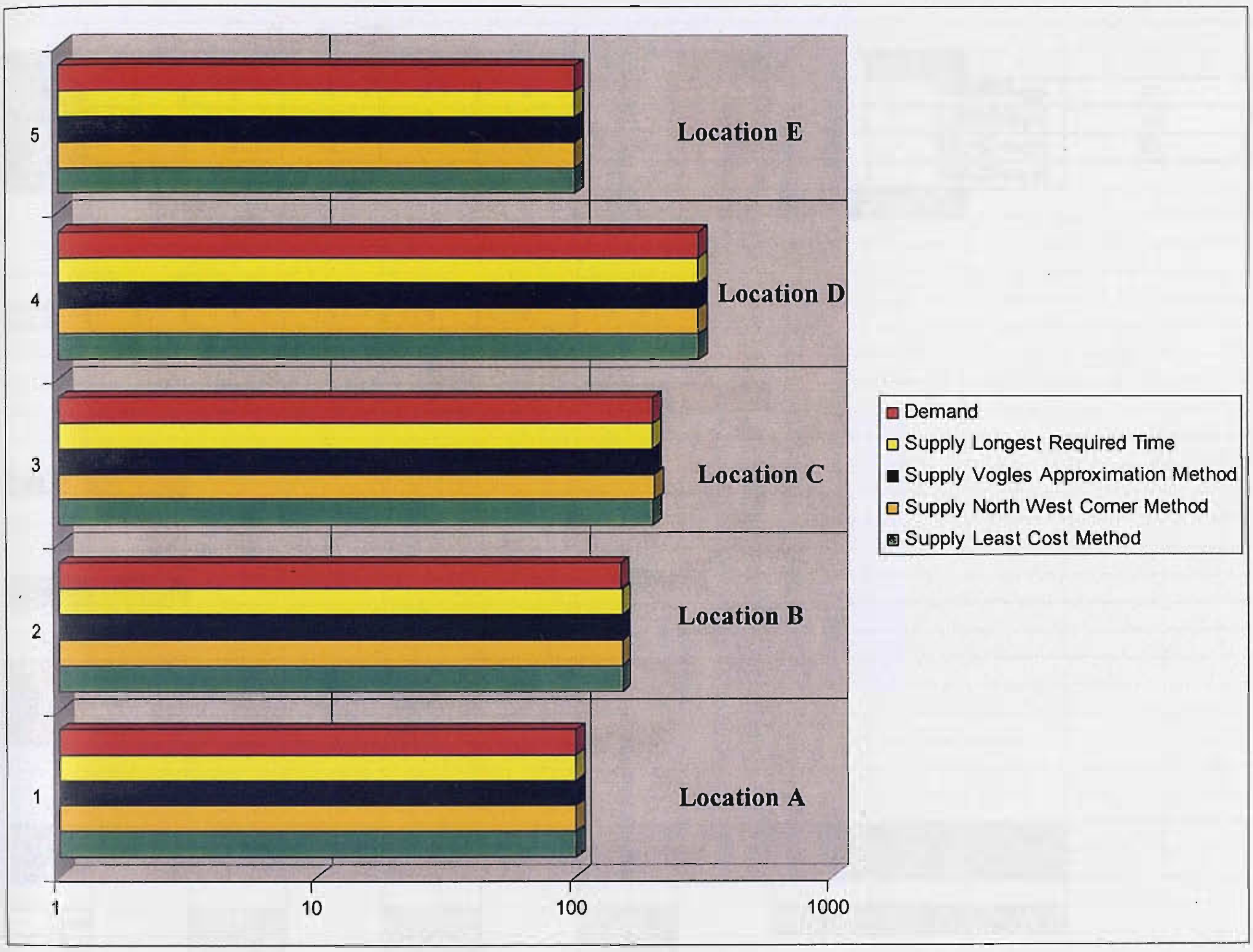


Figure A 1: Demand supply chart

Single Factor Analysis

	Observations (OBS)									
Factors	A	B	C	D	E	Totals		Avg. yi		
Least Cost	0	2	0	0	0	2		0.40	=M1=Avg.y1.	n= 5
North west	0	2	4	0	0	6		1.20	=M2=Avg.y2.	a= 4
Vogels	0	2	0	0	0	2		0.40	=M3=Avg.y3.	N= 20
AD HOC	0	2	0	0	0	2		0.40	=M4=Avg.y4.	
					sum	12	Avg. of Avg.	0.60		

(OBS)^2:-	0	4	0	0	0		
	0	4	16	0	0		
	0	4	0	0	0		
	0	4	0	0	0	Sum	32

(Totals)^2:-	4
	36
	4
	4
sum	48

SST	= Sum(OBS)^2	-	((Totals)^2/N)	=	24.80
SSTreatments	= (Sum (Totals)^2)/n)	-	((Totals)^2/N)	=	2.40
SSE	= SST	-	SSTreatments	=	22.40

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Fo	F.05,3,16 (α = .05	P-Value
Factors	2.40	3	0.80	0.57	3.24	1.028E-05
Error	22.40	16	1.40			
Total	24.80	19				

	Residuals (e(ij))						
Factors	A	B	C	D	E		Avg. yi
Least Cost	-0.40	1.60	-0.40	-0.40	-0.40	M1=Avg.y1.	0.40
North west	-1.20	0.80	2.80	-1.20	-1.20	M2=Avg.y2.	1.20
Vogels	-0.40	1.60	-0.40	-0.40	-0.40	M3=Avg.y3.	0.40
AD HOC	-0.40	1.60	-0.40	-0.40	-0.40	M4=Avg.y4.	0.40
							0.60

Figure A 2: Single factor analysis

Normal probability plot of residuals

Normal probability plot of residuals.

The standard Residual dij= eij/SQRT (MSE)

Where eij= yij - Avg yi

e(ij)	SQRT MSE	d(ij)
-0.40	1.18	-0.34
1.60	1.18	1.35
-0.40	1.18	-0.34
-0.40	1.18	-0.34
-0.40	1.18	-0.34
-1.20	1.18	-1.01
0.80	1.18	0.68
2.80	1.18	2.37
-1.20	1.18	-1.01
-1.20	1.18	-1.01
-0.40	1.18	-0.34
1.60	1.18	1.35
-0.40	1.18	-0.34
-0.40	1.18	-0.34
-0.40	1.18	-0.34
-0.40	1.18	-0.34
1.60	1.18	1.35
-0.40	1.18	-0.34
-0.40	1.18	-0.34
-0.40	1.18	-0.34

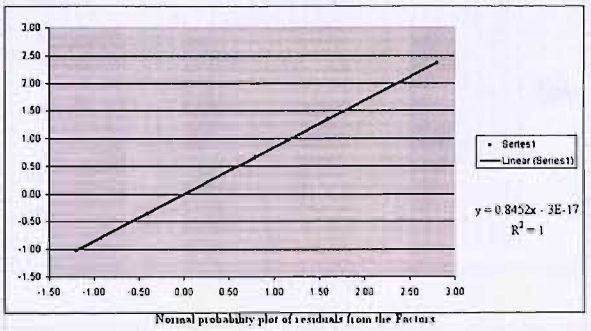


Figure A 3: Normal probability plot of residuals

Plot of residuals versus factor levels

Plot of residuals versus factor levels:

OBS	e(ij)
Least Cost	-0.34
Least Cost	1.35
Least Cost	-0.34
Least Cost	-0.34
Least Cost	-0.34
North west	-1.01
North west	0.68
North west	2.37
North west	-1.01
North west	-1.01
Vogels	-0.34
Vogels	1.35
Vogels	-0.34
Vogels	-0.34
Vogels	-0.34
AD HOC	-0.34
AD HOC	1.35
AD HOC	-0.34
AD HOC	-0.34
AD HOC	-0.34

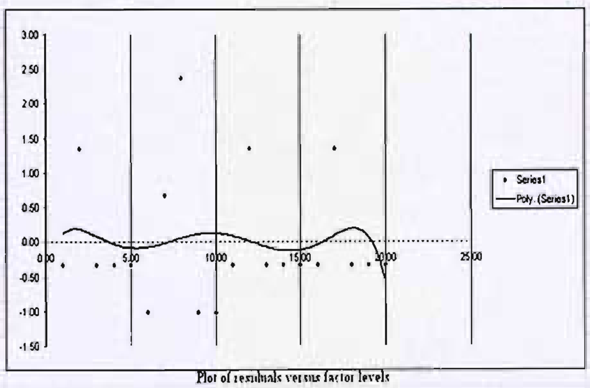
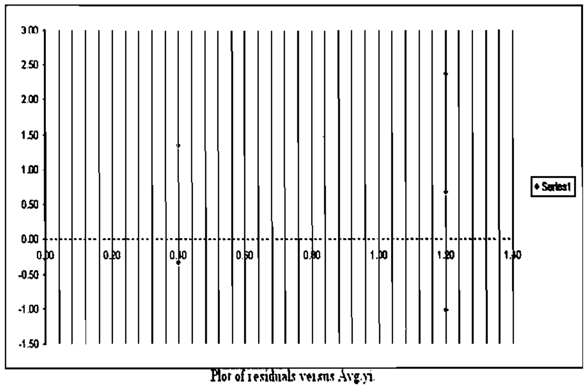


Figure A 4: Plot of residuals versus factor levels

Plot of residuals versus Avg. Yi

Plot of residuals versus Avg.yi:

Avg. yi	e(ij)
0.40	-0.34
0.40	1.35
0.40	-0.34
0.40	-0.34
0.40	-0.34
1.20	-1.01
1.20	0.68
1.20	2.37
1.20	-1.01
1.20	-1.01
0.40	-0.34
0.40	1.35
0.40	-0.34
0.40	-0.34
0.40	-0.34
0.40	-0.34
0.40	1.35
0.40	-0.34
0.40	-0.34
0.40	-0.34



Plot of residuals versus Avg.yi.

Figure A 5: Plot of residuals versus Avg. Yi

Project Site Layout

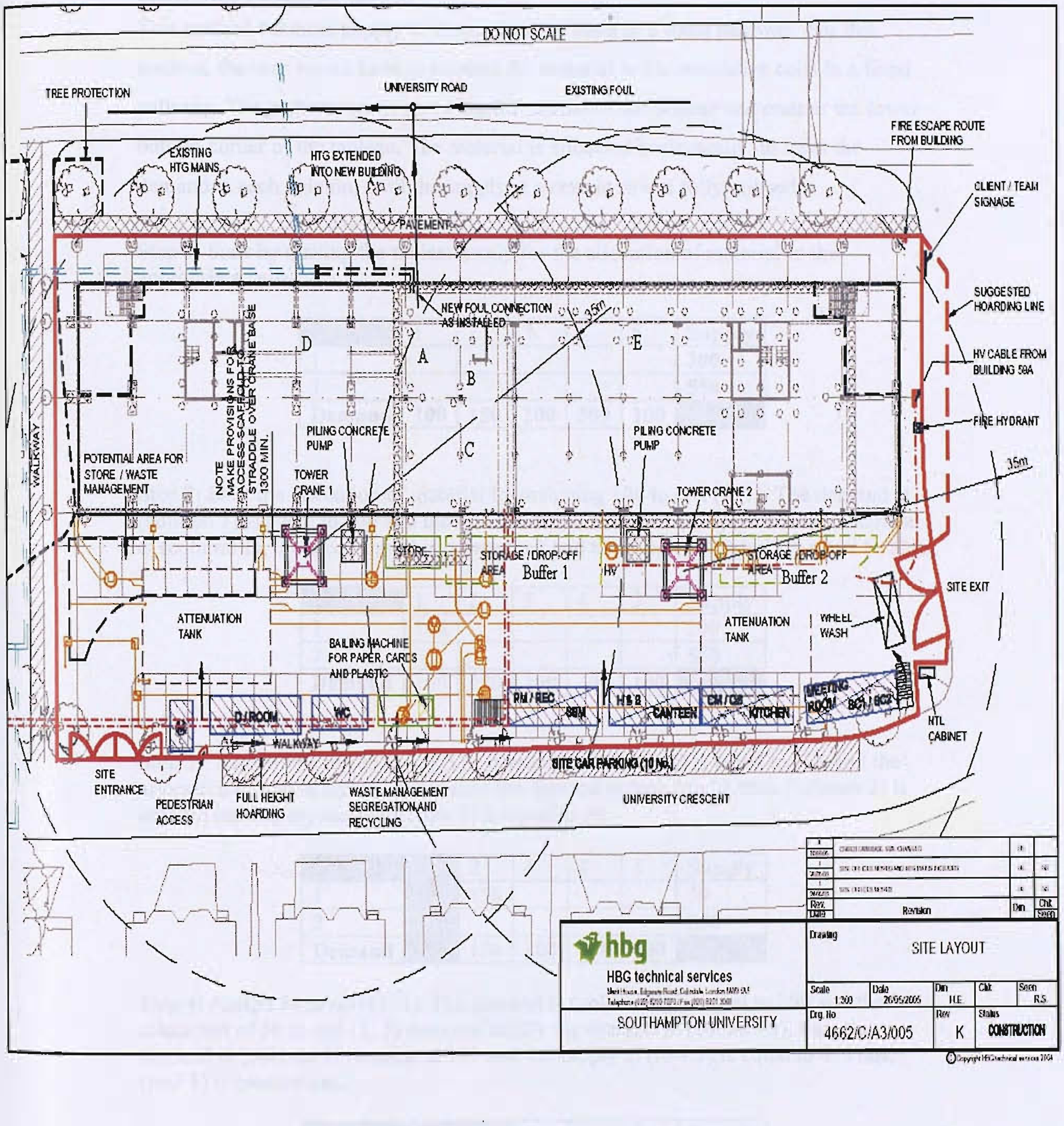


Figure A 6: EEE building project site layout

Appendix B: Detailed Explanation of the Transportation Methods

North West Corner method:

This method balances supply to demand on the basis of a fixed pathway. For this method, the user would have to allocate the material to the respective cells in a fixed pathway. The pathway starts at the top left corner of the tableau and ends at the lower bottom corner of the tableau. The material is allocated horizontally, to meet the demand at each column, until the supply at a certain row is fully utilised.

Step 1: Start by making the tableau ready for the allocation of material to the appropriate cells.

	1	2	3	4	5	**Supply**
1						**300**
2						**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Step 2: Start the allocation of material by assigning 100 to cell (1, 1). The demand at (column 1) is equal to 100 and the allocation of 100 to cell (1, 1) satisfies the demand at (column 1), thus (column 1) is crossed out and the supply at (row 1) is equal to **200**.

	1	2	3	4	5	**Supply**
1	100					**200**
2						**550**
Demand	100	**150**	**200**	**300**	**100**	

Step 3: Assign 150 to cell (1, 2). The demand at (column 2) is equal to 150 and the allocation of 150 to cell (1, 2) satisfies the demand at (column 2), thus (column 2) is crossed out and the supply at (row 1) is equal to **50**.

	1	2	3	4	5	**Supply**
1	**100**	150				**50**
2						**550**
Demand	**100**	150	**200**	**300**	**100**	

Step 4: Assign 50 to cell (1, 3). The demand at (column 3) is equal to 200 and the allocation of 50 to cell (1, 3) does not satisfy the demand at (column 3), thus the demand at (column 3) remains at 150 and the supply at (row 1) is equal to **0**. Thus, (row 1) is crossed out.

	1	2	3	4	5	**Supply**
1	**100**	**150**	50			**0**
2						**550**
Demand	**100**	**150**	200	**300**	**100**	

Step 5: Assign 150 to cell (2, 3). The remaining demand at (column 3) is equal to 150 and the allocation of 150 to cell (2, 3) satisfies the demand at (column 3), thus (column 3) is crossed out and the supply at (row 2) is equal to **400**.

	1	2	3	4	5	Supply
1	**100**	**150**	**50**			**0**
2			150			**400**
Demand	**100**	**150**	200	**300**	**100**	

Step 6: Assign 300 to cell (2, 4). The demand at (column 4) is equal to 300 and the allocation of 300 to cell (2, 4) satisfies the demand at (column 4), thus (column 4) is crossed out and the supply at (row 2) is equal to **100**.

	1	2	3	4	5	Supply
1	**100**	**150**	**50**			**0**
2			**150**	300		**100**
Demand	**100**	**150**	**200**	300	**100**	

Step 7: Assign 100 to cell (2, 5). The demand at (column 5) is equal to 100 and the allocation of 100 to cell (2, 5) satisfies the demand at (column 5), thus (column 5) is crossed out and the supply at (row 2) is equal to **0**. Thus, (row 2) is crossed out.

	1	2	3	4	5	Supply
1	**100**	**150**	**50**			**0**
2			**150**	**300**	100	**0**
Demand	**100**	**150**	**200**	**300**	100	

Step 8: The allocation of the material to the respective cells is successfully completed.

	1	2	3	4	5	Supply
1	**100**	**150**	**50**			**0**
2			**150**	**300**	**100**	**0**
Demand	**100**	**150**	**200**	**300**	**100**	

Step 9: The tableau is completed in respect to the North West corner method.

	1	2	3	4	5	Supply
1	100	150	50			**300**
2			150	300	100	**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Least Cost method:

This method balances supply to demand on the basis of the shortest cycle time per load. For this method, the user would have to allocate the material to the respective cells on the basis of the smallest cycle time per load for each cell. The allocation of material begins at the cell with the smallest cycle time. Once the material demand at a certain column is satisfied or the supply of material at a certain row is fully utilised that respective row or column and its matching row or column of the cycle time are crossed out. The allocation of material to the respective cells continues in the same manner until all cells are satisfied.

Step 1: Start by making the tableau ready for the allocation of material to the appropriate cells.

	1	2	3	4	5	**Supply**
1						**300**
2						**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	**6**	**5**	**3**	7	**7**
2	**8**	7	**4**	**12**	**6**

Step 2: Start the allocation of material by assigning **200** to cell (1, 3). This is because cell (1, 3) has the smallest cycle time in the tableau (**3 minutes**). The demand at (column 3) is equal to **200** and the allocation of **200** to cell (1, 3) satisfies the demand at (column 3), thus (column 3) is crossed out and the supply at (row 1) is equal to **100**.

	1	2	3	4	5	**Supply**
1			200			**100**
2						**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	**6**	**5**	3	7	**7**
2	**8**	7	**4**	**12**	**6**

Step 3: Assign 100 to cell (1, 2), it has the smallest uncrossed-out cycle time (5 minutes). The demand at (column 2) is equal to 150 and the remaining supply at (row 1) is equal to 100. Thus, the allocation of 100 to cell (1, 2) does not satisfy the demand at (column 2). The demand at (column 2) remains at 50 and the supply at (row 1) is equal to 0. Thus, (row 1) is crossed out.

	1	2	3	4	5	Supply
1		100	200			0
2						550
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 4: Assign 100 to cell (2, 5), it has the smallest uncrossed-out cycle time (6 minutes). The demand at (column 5) is equal to 100 and the supply at (row 2) is equal to 550. The allocation of 100 to cell (2, 5) satisfies the demand at (column 5), thus (column 5) is crossed out and the supply at (row 2) is equal to 450.

	1	2	3	4	5	Supply
1		100	200			0
2					100	450
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 5: Assign 50 to cell (2, 2), it has the smallest uncrossed-out cycle time (7 minutes). The remaining demand at (column 2) is equal to 50 and the supply at (row 2) is equal to 450. The allocation of 50 to cell (2, 2) satisfies the demand at (column 2), thus (column 2) is crossed out and the supply at (row 2) is equal to 400.

	1	2	3	4	5	Supply
1		100	200			0
2		50			100	400
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 6: Assign 100 to cell (2, 1), it has the smallest uncrossed-out cycle time (8 minutes). The demand at (column 1) is equal to 100 and the supply at (row 2) is equal to 400. The allocation of 100 to cell (2, 1) satisfies the demand at (column 1), thus (column 1) is crossed out and the supply at (row 2) is equal to 300.

	1	2	3	4	5	Supply
1		100	200			0
2	100	50			100	300
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 7: Assign 300 to cell (2, 4), it is the last remaining cell to be filled in. The demand at (column 4) is equal to 300 and the supply at (row 2) is equal to 300. The allocation of 300 to cell (2, 4) satisfies the demand at (column 4), thus (column 4) is crossed out and the supply at (row 2) is equal to 0. Thus, (raw 2) is crossed out.

	1	2	3	4	5	Supply
1		100	200			0
2	100	50		300	100	0
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 8: The allocation of the material to the respective cells is successfully completed.

	1	2	3	4	5	Supply
1		100	200			0
2	100	50		300	100	0
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 9: The tableau is completed in respect to the Least Cost method.

	1	2	3	4	5	**Supply**
1		**100**	**200**			**300**
2	**100**	**50**		**300**	**100**	**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	**6**	**5**	**3**	7	7
2	**8**	7	**4**	**12**	**6**

Vogel Approximation method:

This method balances supply to demand on the basis of the shortest cycle time per load within the largest penalty. For this method, the user would have to allocate the material to the respective cells on the basis of the following guidelines:

- Calculate the largest Penalty by subtracting the two smallest cycle times for each row and each column.
- The allocation of material begins at the cell with the smallest cycle time located in the row or column with the largest penalty. Once the material demand at a certain column is satisfied or the supply of material at a certain row is fully utilised that respective row or column and its matching row or column of the cycle time are crossed out. The allocation of material to the respective cells continues in the same manner until all cells are satisfied. Once there is only one row or one column left, the allocation of material is continued in respect to the steps of the least cost method.

Step 1: Start by making the tableau ready for the allocation of material to the appropriate cells.

	1	2	3	4	5	**Supply**
1						**300**
2						**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	7	7	
2	**8**	7	**4**	**12**	**6**	
Column Penalty						

Step 2: Start by calculating the largest penalty for all the rows and columns. It turns out that (column 4) has the largest penalty. Identify the cell with the smallest cycle time within (column 4), which is cell (1, 4). Assign 300 to cell (1, 4). The demand at (column 4) is equal to 300 and the allocation of 300 to cell (1, 4) satisfies the demand at (column 4), thus (column 4) is crossed out and the supply at (row 1) is equal to 0. Thus, (row 1) is crossed out.

	1	2	3	4	5	Supply
1				300		0
2						550
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	6	5	3	7	7	5-3=2
2	8	7	4	12	6	6-4=2
Column Penalty	8-6 =2	7-5 =2	4-3 =1	12-7 =5	7-6 =1	

Step 3: Since only one row is left (row 2), the allocation of material to the remaining cells will continue in respect to the least cost method. Assign 200 to cell (2, 3), this is because cell (2, 3) has the smallest cycle time in the tableau (4 minutes). The demand at (column 3) is equal to 200 and the allocation of 200 to cell (2, 3) satisfies the demand at (column 3), thus (column 3) is crossed out and the supply at (row 2) is equal to 350.

	1	2	3	4	5	Supply
1				300		0
2			200			350
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	6	5	3	7	7	
2	8	7	4	12	6	
Column Penalty						

Step 4: Assign 100 to cell (2, 5), it has the smallest uncrossed-out cycle time (6 minutes). The demand at (column 5) is equal to 100 and the supply at (row 2) is equal to 350. The allocation of 100 to cell (2, 5) satisfies the demand at (column 5), thus (column 5) is crossed out and the supply at (row 2) is equal to **250**.

	1	2	3	4	5	**Supply**
1				**300**		**0**
2			**200**		**100**	**250**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	**7**	**7**	
2	**8**	**7**	**4**	**12**	**6**	
Column Penalty						

Step 5: Assign 150 to cell (2, 2), it has the smallest uncrossed-out cycle time (7 minutes). The allocation of 150 to cell (2, 2) satisfies the demand at (column 2), thus (column 2) is crossed out and the supply at (row 2) is equal to **100**.

	1	2	3	4	5	**Supply**
1				**300**		**0**
2		**150**	**200**		**100**	**100**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	**7**	**7**	
2	**8**	7	**4**	**12**	**6**	
Column Penalty						

Step 6: Assign 100 to cell (2, 1), it is the last remaining cell to be filled in. The demand at (column 1) is equal to 100 and the supply at (row 2) is equal to 100. The allocation of 100 to cell (2, 1) satisfies the demand at (column 1), thus (column 1) is crossed out and the supply at (row 2) is equal to 0. Thus, (raw 2) is crossed out.

	1	2	3	4	5	**Supply**
1				**300**		**0**
2	**100**	**150**	**200**		**100**	**0**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	**7**	**7**	
2	**8**	**7**	**4**	**12**	**6**	
Column Penalty						

Step 7: The allocation of the material to the respective cells is successfully completed.

	1	2	3	4	5	**Supply**
1				**300**		**0**
2	**100**	**150**	**200**		**100**	**0**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	**7**	**7**	
2	**8**	**7**	**4**	**12**	**6**	
Column Penalty						

Step 8: The tableau is completed in respect to the Vogel approximation method.

	1	2	3	4	5	**Supply**
1				**300**		**300**
2	**100**	**150**	**200**		**100**	**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5	Row Penalty
1	**6**	**5**	**3**	**7**	**7**	
2	**8**	**7**	**4**	**12**	**6**	
Column Penalty						

Ad Hoc method based on the longest transportation time:

This method balances supply to demand on the basis of the largest cycle time per load. For this method, the user would have to allocate the material to the respective cells on the basis of the largest cycle time per load for each cell. The allocation of material begins at the cell with the largest cycle time. Once the material demand at a certain column is satisfied or the supply of material at a certain row is fully utilised that respective row or column and its matching row or column of the cycle time are crossed out. The allocation of material to the respective cells continues in the same manner until all cells are satisfied.

Step 1: Start by making the tableau ready for the allocation of material to the appropriate cells.

	1	2	3	4	5	Supply
1						**300**
2						**550**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 2: Start the allocation of material by assigning **300** to cell (2, 4). This is because cell (2, 4) has the largest cycle time in the tableau (**12 minutes**). The demand at (column 4) is equal to **300** and the allocation of **300** to cell (2, 4) satisfies the demand at (column 4), thus (column 4) is crossed out and the supply at (row 1) is equal to **250**.

	1	2	3	4	5	Supply
1						**300**
2				300		**250**
Demand	**100**	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 3: Assign 100 to cell (2, 1), it has the largest uncrossed-out cycle time (8 minutes). The demand at (column 1) is equal to 100 and the supply at (row 2) is equal to 250. The allocation of 100 to cell (2, 1) satisfies the demand at (column 1), thus (column 1) is crossed out and the supply at (row 2) is equal to **150**.

	1	2	3	4	5	Supply
1						**300**
2	100			**300**		**150**
Demand	100	**150**	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 4: Assign 150 to cell (2, 2), both cell (2, 2) and cell (2, 5) have the largest uncrossed-out cycle time (7 minutes) but the demand at (column 2) is greater than at (column 5). The demand at (column 2) is equal to 150 and the supply at (row 2) is equal to 150. The allocation of 150 to cell (2, 2) satisfies the demand at (column 2), thus (column 2) is crossed out and the supply at (row 2) is equal to **0**. Thus, (raw 2) is crossed out.

	1	2	3	4	5	Supply
1						**300**
2	**100**	150		**300**		**0**
Demand	**100**	150	**200**	**300**	**100**	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 5: Assign 100 to cell (1, 5), it has the largest uncrossed-out cycle time (7 minutes). The demand at (column 5) is equal to 100 and the supply at (row 1) is equal to 300. The allocation of 100 to cell (1, 5) satisfies the demand at (column 5), thus (column 5) is crossed out and the supply at (row 1) is equal to **200**.

	1	2	3	4	5	Supply
1					100	**200**
2	**100**	**150**		**300**		**0**
Demand	**100**	**150**	**200**	**300**	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 6: Assign 200 to cell (1, 3), it is the last remaining cell to be filled in. The demand at (column 3) is equal to 200 and the supply at (row 1) is equal to 200. The allocation of 200 to cell (1, 3) satisfies the demand at (column 3), thus (column 3) is crossed out and the supply at (row 1) is equal to 0. Thus, (raw 1) is crossed out.

	1	2	3	4	5	Supply
1			200		100	0
2	100	150		300		0
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 7: The allocation of the material to the respective cells is successfully completed.

	1	2	3	4	5	Supply
1			200		100	0
2	100	150		300		0
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Step 8: tableau is completed in respect to the Ad Hoc method.

	1	2	3	4	5	Supply
1		100	200			0
2	100	50		300	100	0
Demand	100	150	200	300	100	

Cycle time in minutes For Each Cell	1	2	3	4	5
1	6	5	3	7	7
2	8	7	4	12	6

Appendix C: Tables and Figures of the EEE Building Site

EEE Site Plan West Panel Elevation

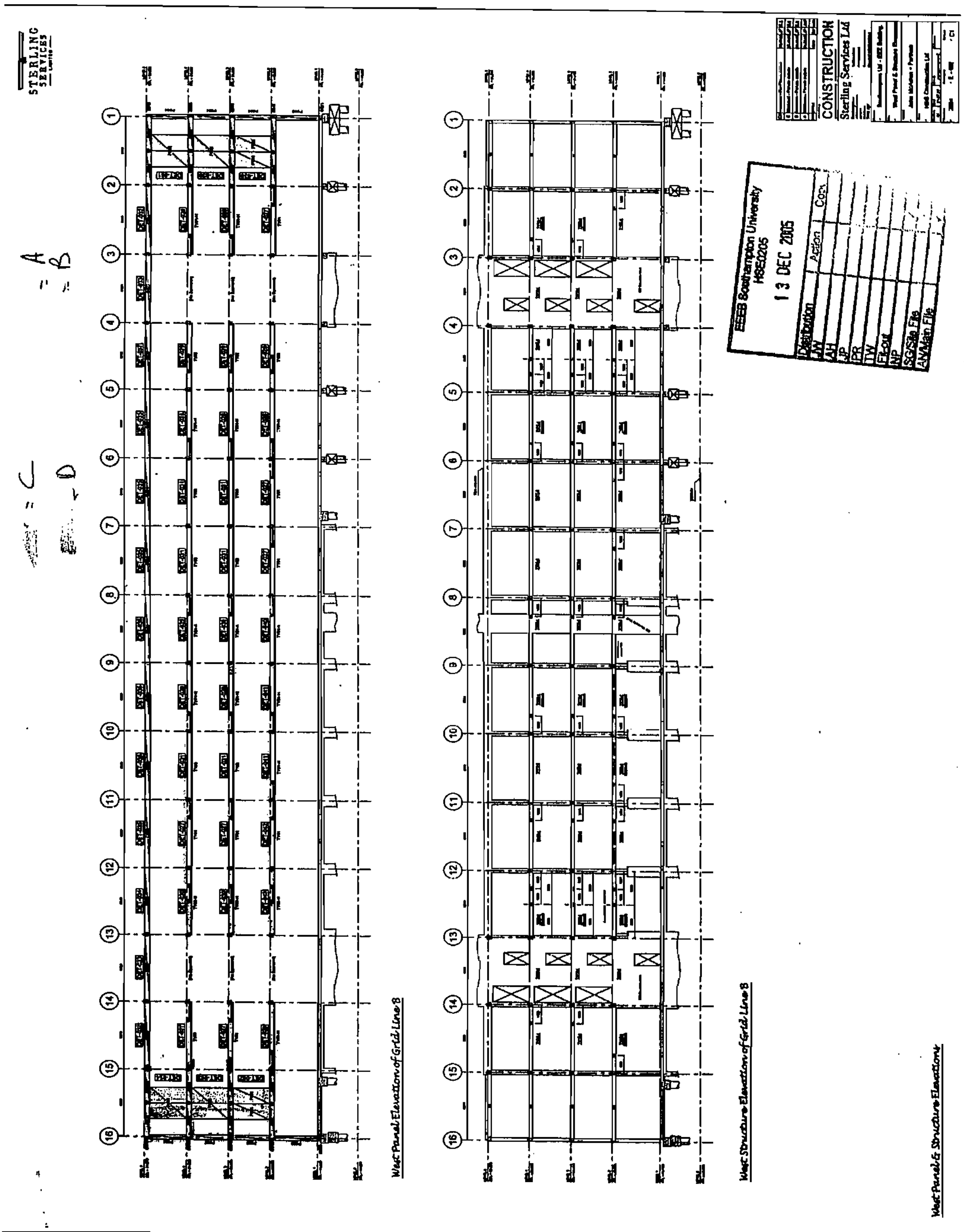


Figure C 1: EEE site plan West panel elevation

EEE Site Plan North and south Panel Elevation

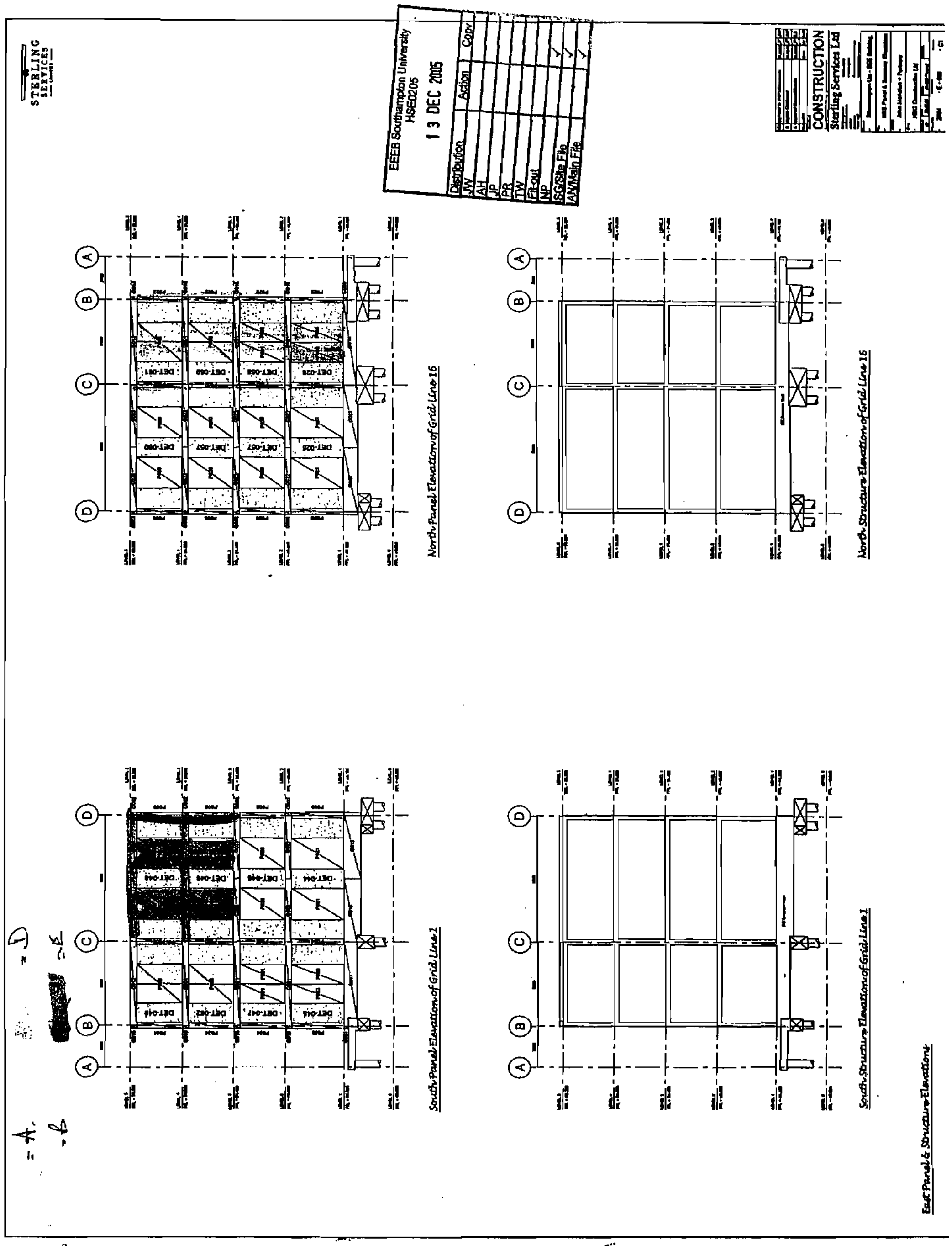


Figure C 2: EEE site plan North and South panel elevation

EEE Site Plan East Panel Elevation

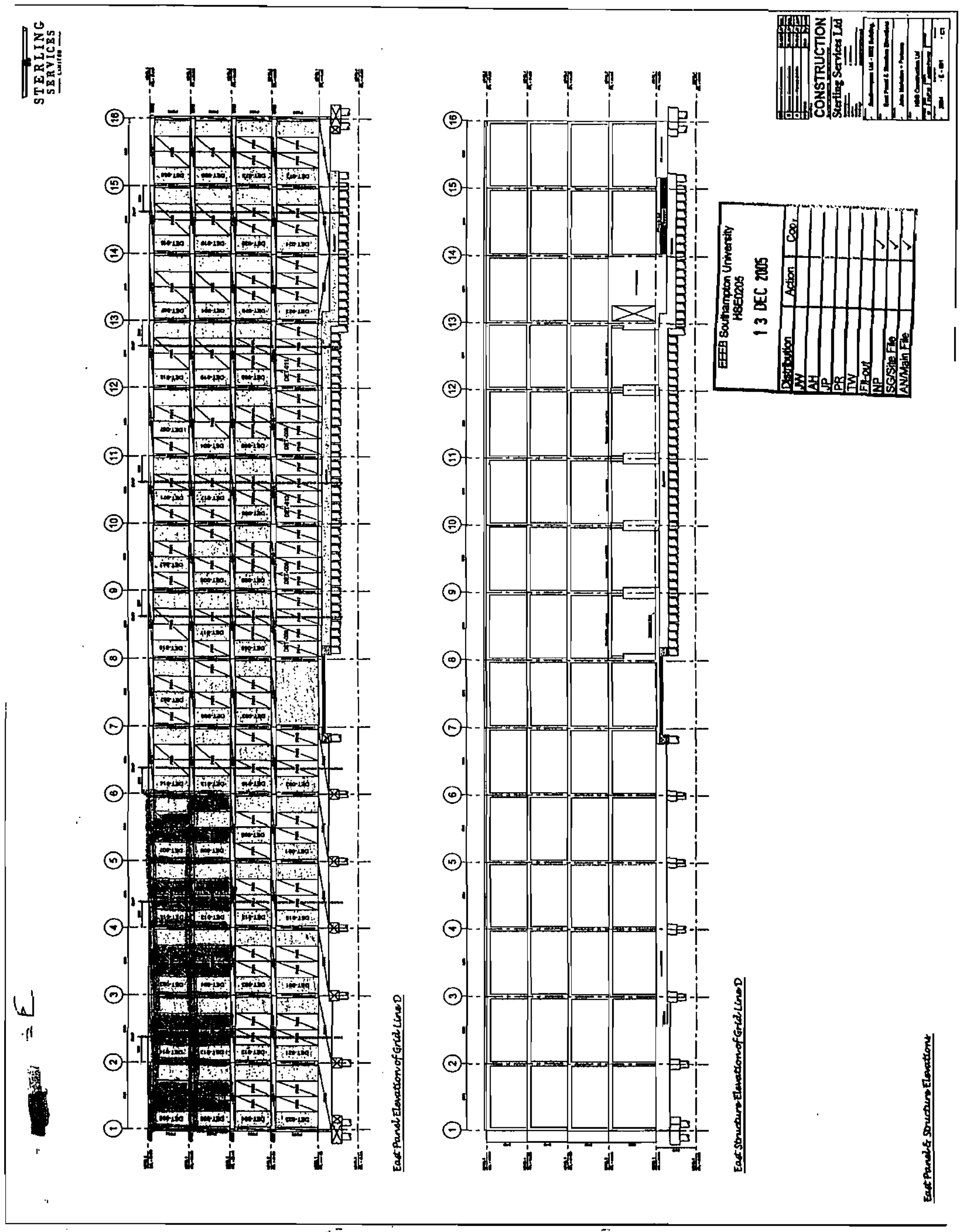


Figure C 3: EEE site plan East panel elevation

SOUTHAMPTON DELIVERY SCHEDULE 003 **DATE: 28/11/05**

DELIVERY DATE	LOAD	PANEL NUMBERS
06/12/2005	1	G021, G017, G016, G015, G003, G004, G005 X 3, P009, P004 X 5
13/12/2005	2	P003 X 12
16/12/2005	3	G040, G041. G019. G022, G023, G002, G001 X 5, P021 X 2, P025, P004 X 2, P013, G006
21/12/2005	4	P020 X 2, P001 X 8, P008, P002 X 4, P024
04/01/2006	5	G032, G033, G019, G022, G023, G001 X 5, G009, G010, G011, G007, G013, G014, G020, G002
25/01/2006	6	P007 X 5, P003 X 2, P018, P004 X 3
06/02/2006	7	P006 X 2, P019, P015 X 3, P016 X 2, P003 X 2
08/02/2006	8	P021 X 2, P003 X 2, P009, P004, P023
10/02/2006	9	G001 X 11, G008, G022, G023, G002, G042, G043, G018
16/02/2006	10	P002 X 12, P008, P022
21/02/2006	11	P001 X 10
23/02/2006	12	P001 X 10
27/02/2006	13	P001 X 4, P020 X 2
01/03/2006	14	G001 X 13. G022. G023, G002, G018, G036, G037
07/03/2006	15	P024, P002 X 6, P008. P005 X 2, P020 X 2
09/03/2006	16	P005B X 2. P005, P001 X 2
10/03/2006	17	G032, G033, G019, G001 X 6, G022, G023, G002
14/03/2006	18	P024, P008, P002 X 5, P002 X 2, P020 X 2
16/03/2006	19	P005 X 3. P005A
17/03/2006	20	G034, G035, G019, G002, G012 X 5. G025, G026
21/03/2006	21	P002 X 10, P008, P022, P020 X 2, P005 X 2
27/03/2006	22	P005 X 6
28/03/2006	23	P001 X 8
30/03/2006	24	G001 X 11. G022. G023, G002, G018, G036, G037
05/04/2006	25	P002 X 11, P008. P022
10/04/2006	26	P005 X 6
11/04/2006	27	P001 X 8
13/04/2006	28	P020 X 2, P005 X 2
17/04/2006	29	G012 X 12, G002. G025, G026, G018, G038, G039
13/02/2006	9A	West Elevation Spandrels
22/02/2006	11A	West Elevation Spandrels

STERLING SERVICES LTD

Figure C 4: EEE site plan material delivery schedule

EEE Building Construction Site Feedback Form

HBG Construction Limited	EEE Building , University Crescent, Southampton, Hampshire, SO17 1BJ
South East	Telephone (02380) 558037 / Fax (02380) 558036 / www.hbgc.co.uk

Mr B Al-Sasi	Date	26th May 2006
Construction Management Research Group University of Southampton SO17 1BJ	Your reference	ref
	Our reference	MGA/TW/SE0205
	Telephone	(07717) 660354
	Fax	(02380) 512483
	E-mail	twarren@hbgc.co.uk

Subject EEE Building, University of Southampton

Dear Basil

We thank you for attending site and introducing us to your programme to plan and monitor the Stone Cladding system being used on the EEE Building project. The system itself seemed to work well with the initial installation sequencing and it was a pity the programme was well under way before we met you. We feel the programme offers great potential and wish you well in developing it further which would be of benefit to future projects.

We hope you continue to do well in your studies and if there is any further information required please contact the writer.

Yours sincerely

HBG Construction Limited - South East

A Warren

Senior Site Manager

Internal cc.	Simon Gray,NC/MFSE0205

Registered office: Merit House, Edgware Road, Colindale, London NW9 5AF. Registered in England: 2379469

HBG is an operating company of Royal BAM Group

Figure C 5: EEE building construction site feedback form

Appendix D: Tables and Figures of the ISVR Building Site

ISVR Site Plan North Panel Elevation

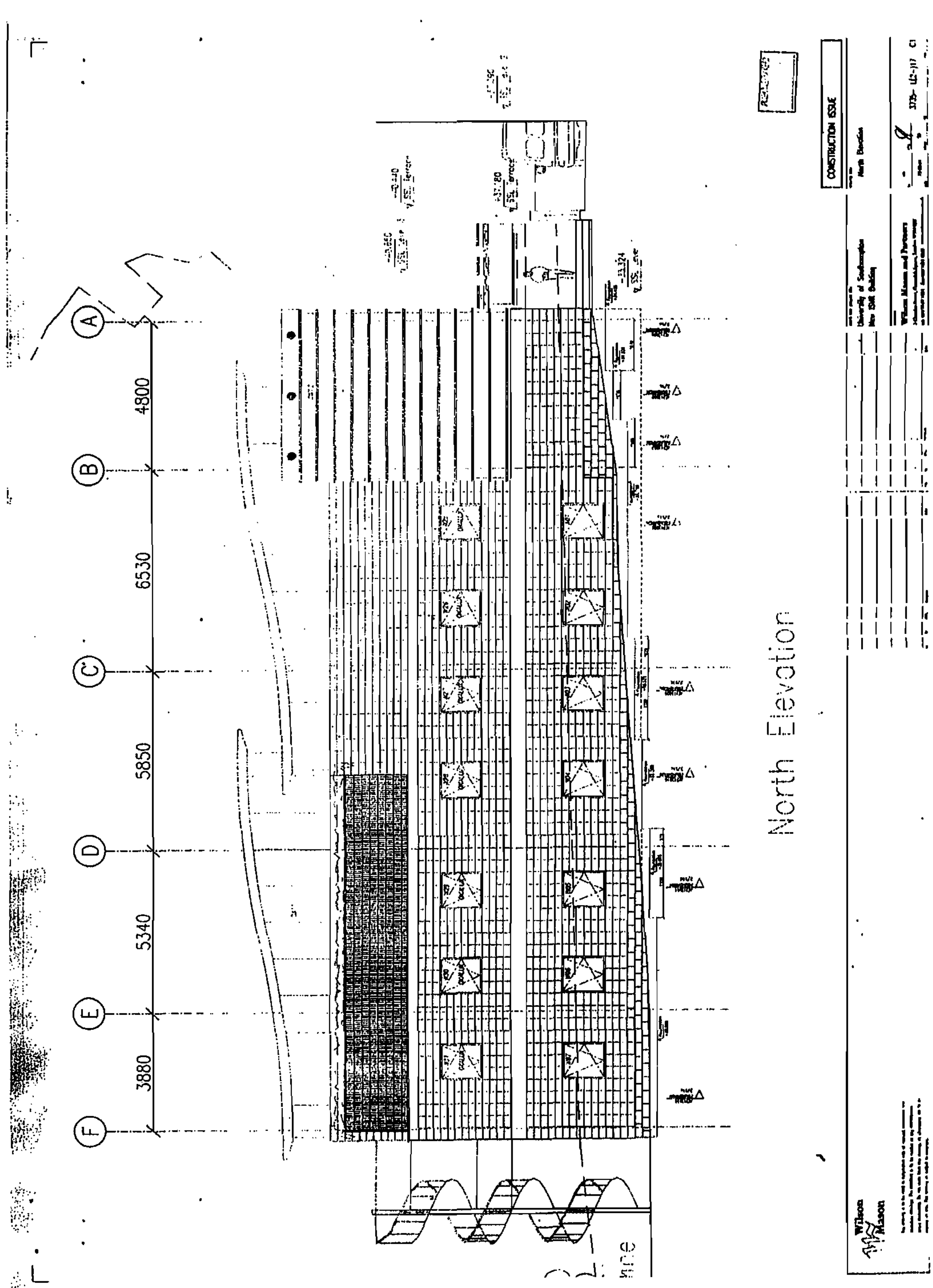


Figure D 1: ISVR site plan North panel Elevation

<u>**ISVR Site Plan South Panel Elevation**</u>

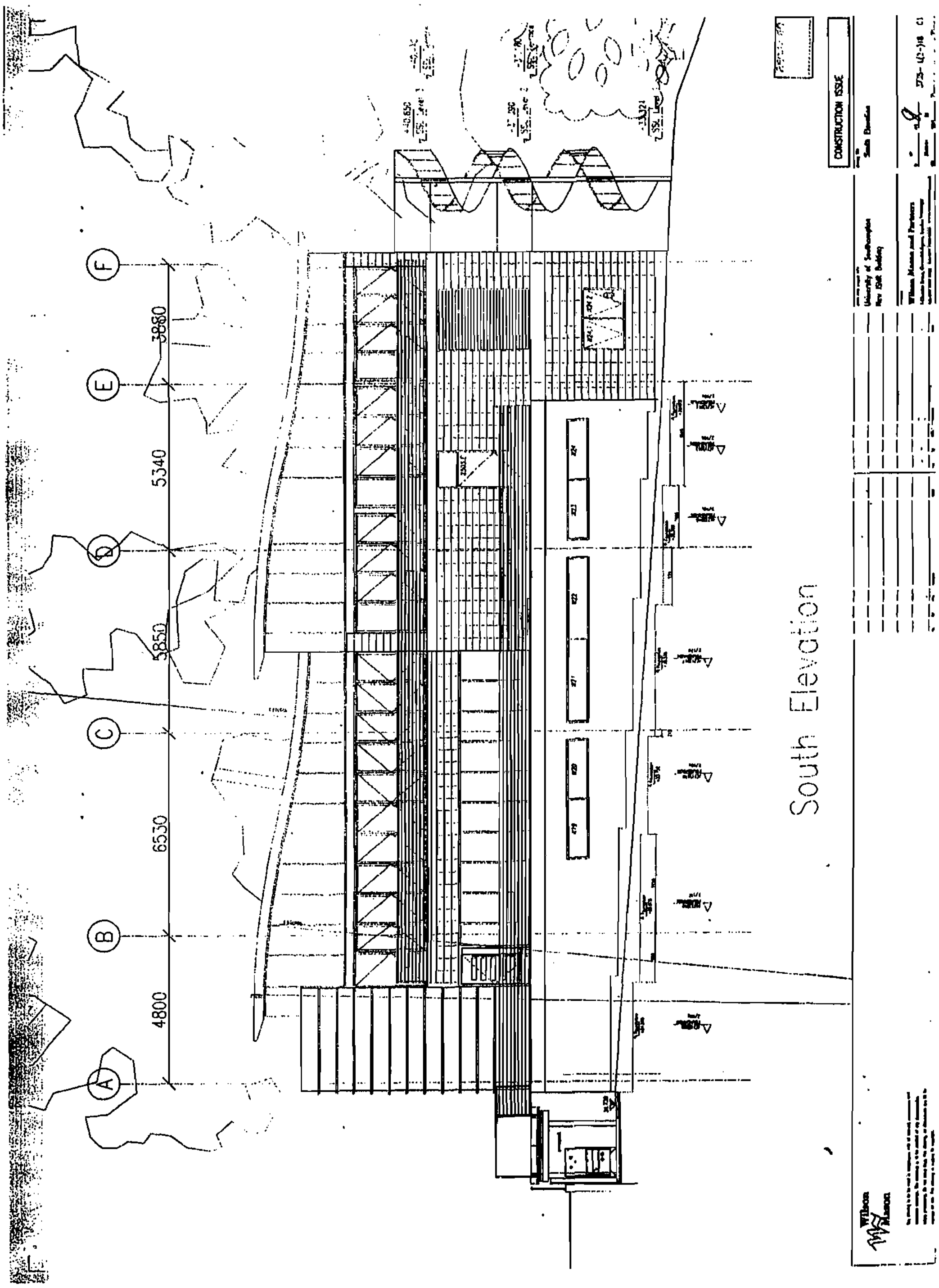


Figure D 2: ISVR site plan South panel Elevation

ISVR Site Plan East Panel Elevation

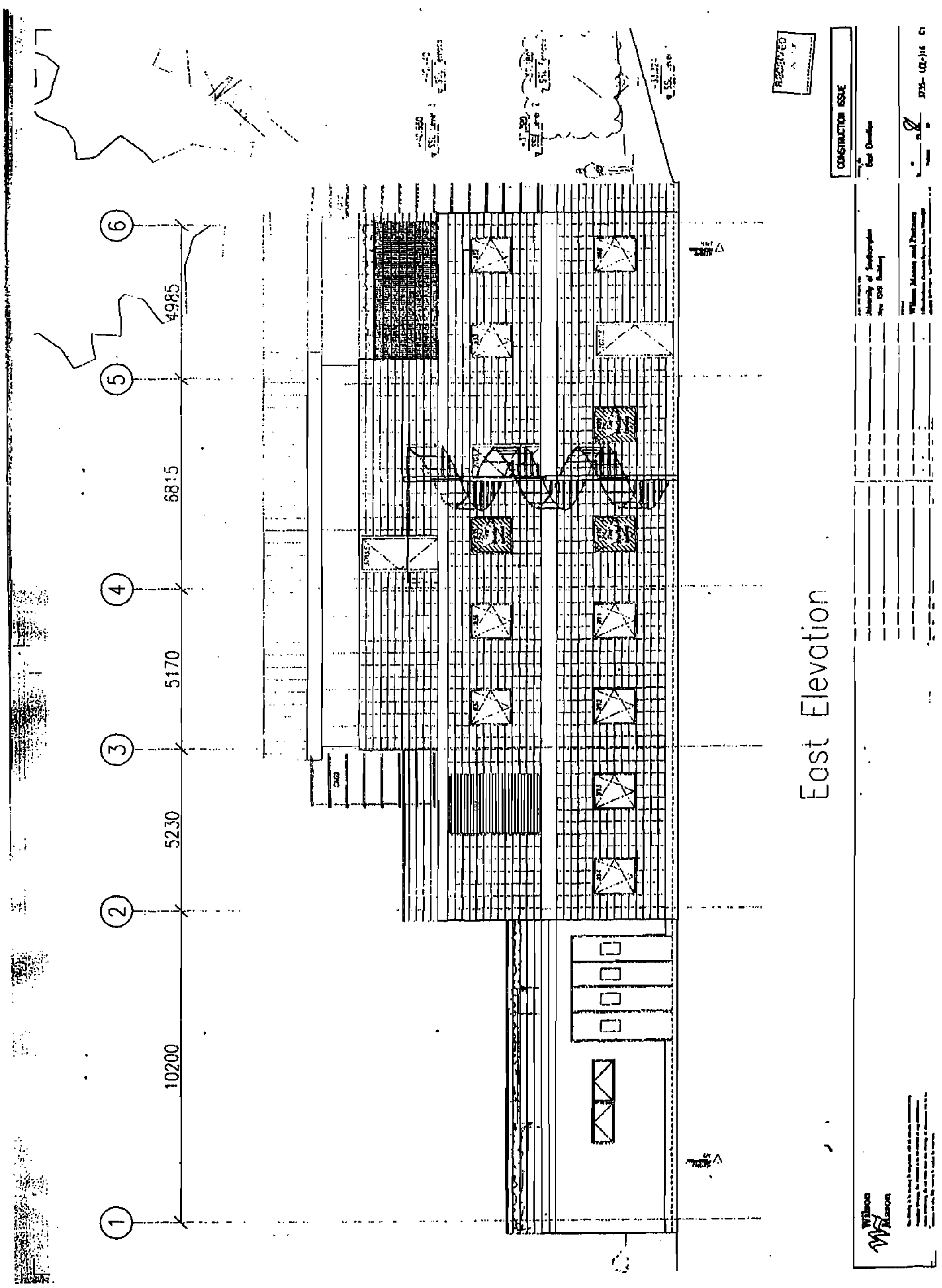


Figure D 3: ISVR site plan East panel Elevation

ISVR Site Plan West Panel Elevation

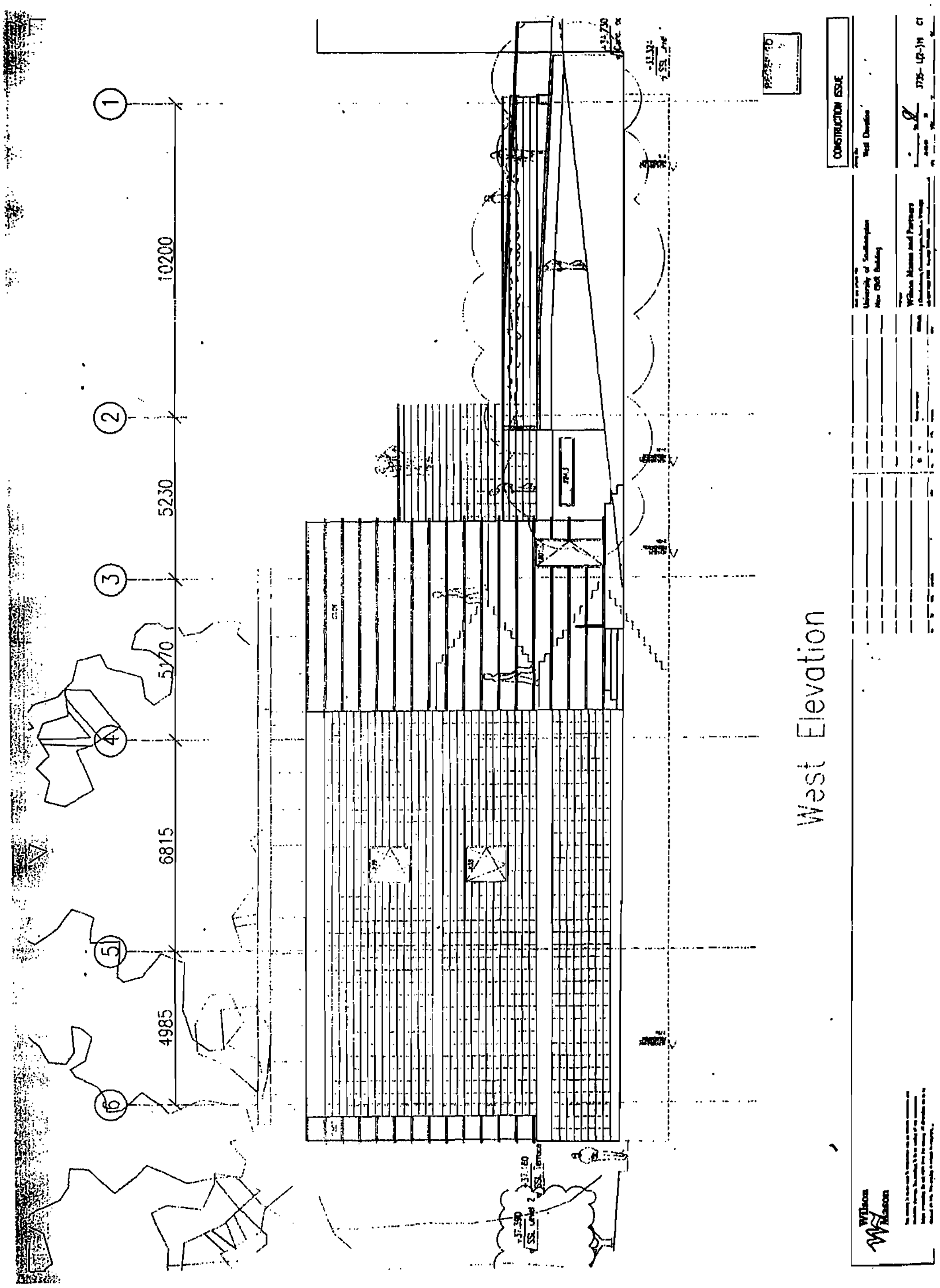


Figure D 4: ISVR site plan West panel Elevation

ISVR Building Construction Site Feedback Form

bluestone

I.S.V.R.
64,Granby Grove,
Highfield,
Southampton
Hampsahire
SO17 3RZ
Tel. 02380 552621
Fax. 02380 678674

27-09-06

Terracotta tiling.

The terracotta tiling is used for a rain screen cladding system.
We looked at the areas of work, the tile type needed at that location, and the quantity required.
Buffer zones were chosen and the quantity required moved from the main storage area to that zone.
Initial times and quantities were calculated and used for the exercise, this gave a rate for the day which was monitored for 2 days to see if it made true. Having found the process was actually slower, new data was calculated and input into the system.
This new data was much more realistic and only after a couple of working days it was noticed that the cladding was progressing with the calculated working time, therefore no changes were made and work was completed in keeping with that allocated by the program.
The rest of the tiles for the other elevations ran true to the calculated times, therefore after an initial calculation and its figures changed accordingly a realistic program could be produced.
I would say that this worked and could give us a fairly accurate forecast of the progression of the works.
The only real problem we had was, the site was is very tight for space with lots of other trades vying for this space, thus the storage area was forever moving although the buffer zones remained.
Calculations were made for other elements of the tiling such as corners, mitred windows tiles and rebate tiles, these of which appear to be working also.

Gray Clarke.
Bluestones Site engineer.

A MORGAN SINDALL COMPANY

Registered Office: 77 Newman Street, London W1T 3EW. Registered in England and Wales, Company No. 4273754

Figure D 5: ISVR building construction site feedback form

Appendix E: Pilot Survey

Sample 1

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☑ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	4
Material Damage due to poor on-site material handling	2
Incorrect batch sizing of predefined loads of material	1
Delays on preplanned cycle times of material loads	3
Other (If other is the most common mistake please specify)	☐

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☐	Low ☑
Tuesday	High ☐	Medium ☑	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☐ ☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: **Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)**	High (40) Medium (35) Low (25)	% % %

Sample 2

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐
7. Please number the specified mistakes listed below from 1 to 5 (1 = most common, 5 = least common) Material is not supplied to the original location of demand as planed Material Damage due to poor on-site material handling Incorrect batch sizing of predefined loads of material Delays on preplanned cycle times of material loads Other (If other is the most common mistake please specify) →		 [illegible] [illegible] [illegible] [illegible] [illegible]
8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below: (High = large amount of work, Medium = intermediate amount of work, Low = small amount of work) Monday — High ☑ — Medium ☑ — Low ☐ Tuesday — High ☑ — Medium ☐ — Low ☐ Wednesday — High ☑ — Medium ☐ — Low ☐ Thursday — High ☐ — Medium ☑ — Low ☐ Friday — High ☐ — Medium ☐ — Low ☑		
9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	High ( ) Medium ( ) Low ( )	 % % %

Sample 3

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes	☑
	No	☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes	☑
	No	☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday	☐
	Tuesday	☑
	Wednesday	☑
	Thursday	☑
	Friday	☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday	☐
	Tuesday	☑
	Wednesday	☑
	Thursday	☑
	Friday	☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	3 ☐
Material Damage due to poor on-site material handling	5 ☐
Incorrect batch sizing of predefined loads of material	4 ☐
Delays on preplanned cycle times of material loads	2 ☐
Other (If other is the most common mistake please specify) ➔	1 ☐

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☐	Low ☑
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes	☑
	No	☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High ( )	%
Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	Medium ( )	%
	Low ( )	%

Sample 4

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes	☑
	No	☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes	☑
	No	☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☑
	Friday	☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	4
Material Damage due to poor on-site material handling	3
Incorrect batch sizing of predefined loads of material	1
Delays on preplanned cycle times of material loads	2
Other (If other is the most common mistake please specify)	☐

→

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☐	Low ☑
Tuesday	High ☐	Medium ☑	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☑	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes	☐
	No	☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (40)	%
Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	Medium (40)	%
	Low (20)	%

Sample 5

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
<u>(1 = most common, 5 = least common)</u>

Material is not supplied to the original location of demand as planed	1
Material Damage due to poor on-site material handling	3
Incorrect batch sizing of predefined loads of material	2
Delays on preplanned cycle times of material loads	4
Other (If other is the most common mistake please specify)	☒

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

<u>(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)</u>

Monday	High ☑	Medium ☐	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☐	Medium ☑	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☑	Medium ☐	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☐ ☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	High (~~3~~ 65) % Medium (25) % Low (10) %	

Sample 6

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers? ACCIDENTS SEEM TO HAPPEN ON ANY DAY NORMALLY TIME RELATED. 1ST THING IN MORNING OR LASTEST TIME OF DAY	Monday Tuesday Wednesday Thursday Friday	☑ ☑ ☑ ☑ ☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers? N/A	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	5
Material Damage due to poor on-site material handling	[illegible]
Incorrect batch sizing of predefined loads of material	[illegible]
Delays on preplanned cycle times of material loads	[illegible]
Other (If other is the most common mistake please specify)	☐

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☑ ☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	High (60) % Medium (30) % Low (10) %	

Sample 7

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers? *am or pm.*	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☑ ☑

7. Please number the specified mistakes listed below from 1 to 5

(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	1
Material Damage due to poor on-site material handling	[illegible]
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Other (If other is the most common mistake please specify)	☐

➔ *incorrect communication*

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☒	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☑	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	High (______) % Medium (______) % Low (______) %	

Sample 8

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☑ ☐
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	4
Material Damage due to poor on-site material handling	1
Incorrect batch sizing of predefined loads of material	2
Delays on preplanned cycle times of material loads	3
Other (If other is the most common mistake please specify)	5

→

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: **Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)**	High ( ) Medium ( ) Low ( )	 % % %

Sample 9

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
<u>(1 = most common, 5 = least common)</u>

Material is not supplied to the original location of demand as planed	[2]
Material Damage due to poor on-site material handling	[1]
Incorrect batch sizing of predefined loads of material	[3]
Delays on preplanned cycle times of material loads	[4]
Other (If other is the most common mistake please specify)	☐

→

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

<u>(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)</u>

Monday	High ☐	Medium ☐	Low ☑
Tuesday	High ☐	Medium ☑	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category: <u>Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)</u>	High (_______) Medium (_______) Low (_______)	 % % %

Sample 10

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes	☑
	No	☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes	☑
	No	☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
5. Which specific day within a working week shows the highest number of mistakes, caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
6. Which specific day within a working week shows the lowest number of mistakes, caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	1
Material Damage due to poor on-site material handling	4
Incorrect batch sizing of predefined loads of material	3
Delays on preplanned cycle times of material loads	2
Other (If other is the most common mistake please specify)	5

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☑	Medium ☐	Low ☐
Tuesday	High ☐	Medium ☑	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage allocations? Based on statistics, High = 70%, Medium = 25%, Low = 5 %	Yes	☒
	No	☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (48) %	
Important Note High (Number %) + Medium (Number %) + Low (Number) % = (must add up to 100%)	Medium (48) %	
	Low (5) %	

Sample 11

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes ☑ No ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes ☐ No ☑
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday ☐ Tuesday ☑ Wednesday ☑ Thursday ☑ Friday ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday ☑ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ N/A Thursday ☐ Friday ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Other (If other is the most common mistake please specify)	☐

➔ Labour level most likely to be lower on Monday (subcontract Environment)

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = Intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☑	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes ☐ No ☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (85-100) % Medium (50-85) % Low (0-50) %

The above is difficult to attain, depending on trade - ability eg: if task is technical or mundane and depending on task duration.

Sample 12

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☐ ☑
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☑ ☑ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	[1]
Material Damage due to poor on-site material handling	[3]
Incorrect batch sizing of predefined loads of material	[4]
Delays on preplanned cycle times of material loads	[2]
Other (If other is the most common mistake please specify) ➔	☐

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☑	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High ( ) % Medium ( ) % Low ( ) %	

Sample 13

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	3 ☐
Material Damage due to poor on-site material handling	3 ☐
Incorrect batch sizing of predefined loads of material	3 ☐
Delays on preplanned cycle times of material loads	3 ☐
Other (If other is the most common mistake please specify) →	3 ☐

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☑	Medium ☑	Low ☐
Wednesday	High ☑	Medium ☑	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (______) % Medium (______) % Low (______) %	

Sample 14

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☑
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	2
Material Damage due to poor on-site material handling	☑
Incorrect batch sizing of predefined loads of material	3
Delays on preplanned cycle times of material loads	4
Other (If other is the most common mistake please specify)	☐

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☑	Low ☐
Tuesday	High ☐	Medium ☐	Low ☐
Wednesday	High ☑	Medium ☐	Low ☐
Thursday	High ☑	Medium ☐	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (______) % Medium (______) % Low (______) %	

Sample 15

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes	☑
	No	☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes	☑
	No	☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday	☐
	Tuesday	☑
	Wednesday	☐
	Thursday	☐
	Friday	☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	[4]
Material Damage due to poor on-site material handling	[4]
Incorrect batch sizing of predefined loads of material	[6]
Delays on preplanned cycle times of material loads	[4]
Other (If other is the most common mistake please specify)	☐

→

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☑	Medium ☐	Low ☐
Tuesday	High ☑	Medium ☐	Low ☐
Wednesday	High ☐	Medium ☑	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☐	Medium ☑	Low ☐

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes	☐
	No	☑
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (100) %	
	Medium (75) %	
	Low (60) %	

Sample 16

1. Is there a relationship between the workers performance output rate and the specific working day of a working week?	Yes No	☑ ☐
2. Do you think that the workers performance output fluctuation is determined by the specific working day they are working in?	Yes No	☑ ☐
3. Which specific day within a working week shows the highest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
4. Which specific day within a working week shows the lowest performance output rate of workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
5. Which specific day within a working week shows the highest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
6. Which specific day within a working week shows the lowest number of mistakes caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐

7. Please number the specified mistakes listed below from 1 to 5
(1 = most common, 5 = least common)

Material is not supplied to the original location of demand as planed	2 ☐
Material Damage due to poor on-site material handling	1 ☐
Incorrect batch sizing of predefined loads of material	3 ☐
Delays on preplanned cycle times of material loads	4 ☐
Other (If other is the most common mistake please specify)	☐

➔

8. If a working week is divided into 3 categories (High, Medium, Low) in which the weekly workload is allocated, classify each specific working day according to the categories specified below:

(High = large amount of work, Medium = intermediate amount of work, Low = small amount of work)

Monday	High ☐	Medium ☐	Low ☑
Tuesday	High ☐	Medium ☑	Low ☐
Wednesday	High ☐	Medium ☑	Low ☐
Thursday	High ☐	Medium ☑	Low ☐
Friday	High ☐	Medium ☐	Low ☑

9. For a working week divided into (High, Medium, and Low) do you agree with the following percentage projected output? Based on statistics, High = 100%, Medium = 35%, Low = 10 %	Yes No	☑ ☐
10. If you answered question 9 with "No", specify a percentage you think is appropriate for each category:	High (______) % Medium (______) % Low (______) %	

Appendix F: Full Survey

Sample 1

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☒
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☒
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☒
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	

Sample 2

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	■
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	■
	Friday	☐

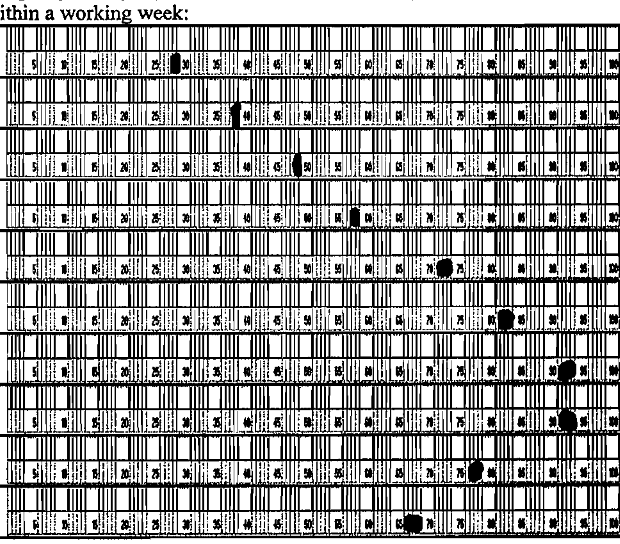
3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ■
- Material Damage due to poor on-site material handling ■
- Incorrect batch sizing of predefined loads of material ■
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	



Sample 3

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☒
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☒
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Monday PM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Tuesday AM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Tuesday PM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Wednesday AM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Wednesday PM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Thursday AM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Thursday PM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Friday AM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Friday PM	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100

Sample 4

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☑
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☑
	Friday	☐

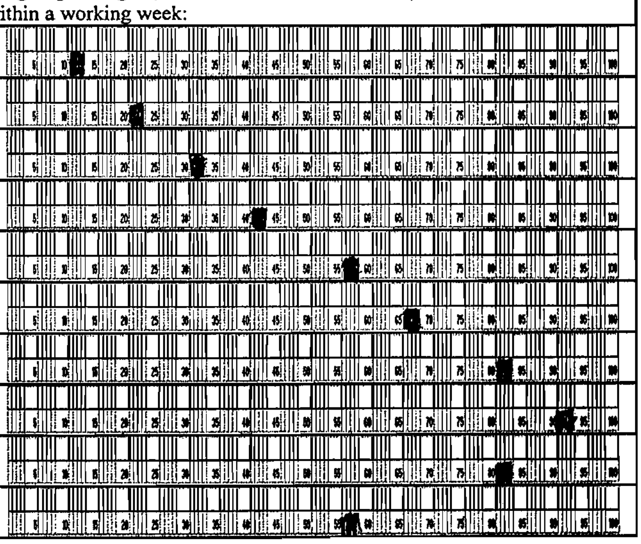
3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☑
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

→ ____

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	



Sample 5

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Monday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Sample 6

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or (accidents) caused by construction workers? *Physical or material*	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or (accidents) caused by construction workers? *Physical or material*	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☑
	Friday	☐

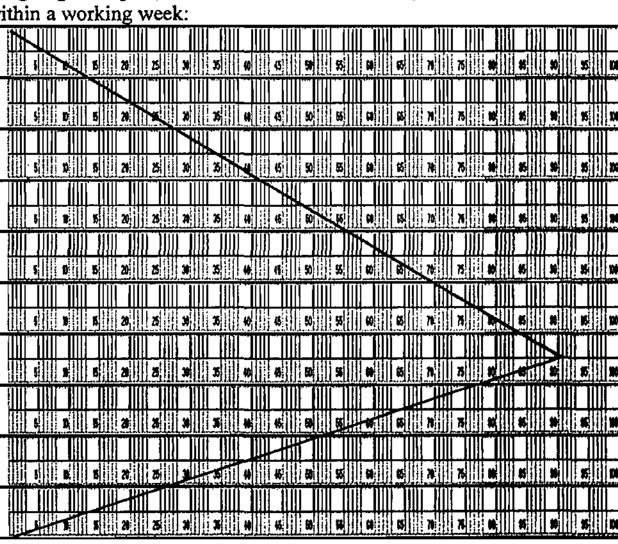
3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☑

→ *MATERIALS NOT DELIVERED TO SITE IN TIME.*

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM
Monday PM
Tuesday AM
Tuesday PM
Wednesday AM
Wednesday PM
Thursday AM
Thursday PM
Friday AM
Friday PM



Sample 7

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☒ ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☒ ☐ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☒
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	✓ 70	80	90	100
Monday PM	10	20	30	40	50	60	✓ 70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	✓ 80	90	100
Tuesday PM	10	20	30	40	50	✓ 60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	✓ 80	90	100
Wednesday PM	10	20	30	40	50	60	70	✓ 80	90	100
Thursday AM	10	20	30	40	50	60	✓ 70	80	90	100
Thursday PM	10	20	30	40	50	60	✓ 70	80	90	100
Friday AM	10	20	30	40	50	60	70	✓ 80	90	100
Friday PM	10	20	30	✓ 40	50	60	70	80	90	100

Sample 8

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Shift	10	20	30	40	50	60	70	80	90	100
Monday AM	10	20	30	40	(50)	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	(80)	90	100
Tuesday AM	10	20	30	(40)	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	(70)	80	90	100
Wednesday AM	10	20	30	40	50	60	(70)	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	(90)	100
Thursday AM	10	20	(30)	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	(60)	70	80	90	100
Friday AM	10	(20)	30	40	50	60	70	80	90	100
Friday PM	10	20	(30)	40	50	60	70	80	90	100

Sample 9

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 10

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	✓40	50	60	70	80	90	100
Monday PM	10	20	30	40	✓50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	✓70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	✓80	90	100
Wednesday AM	10	20	30	40	50	60	70	✓80	90	100
Wednesday PM	10	20	30	40	✓50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	✓80	90	100
Thursday PM	10	20	30	40	50	60	✓70	80	90	100
Friday AM	10	20	30	40	50	60	✓70	80	90	100
Friday PM	10	20	30	✓40	50	60	70	80	90	100

Sample 11

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

	10	20	30	40	50	60	70	80	90	100
Monday AM			✓							
Monday PM							✓			
Tuesday AM				✓						
Tuesday PM						✓				
Wednesday AM					✓					
Wednesday PM					✓					
Thursday AM						✓				
Thursday PM				✓						
Friday AM								✓		
Friday PM		✓								

Sample 12

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	X 50	60	70	80	90	100
Monday PM	10	20	30	40	50	X 60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	X 70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	X 80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	X 90	100
Wednesday PM	10	20	30	40	50	60	70	80	X 90	100
Thursday AM	10	20	30	40	50	60	70	X 80	90	100
Thursday PM	10	20	30	40	50	60	X 70	80	90	100
Friday AM	10	20	30	40	50	X 60	70	80	90	100
Friday PM	10	20	30	40	X 50	60	70	80	90	100

Sample 13

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☑
	Wednesday	☐
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	✓30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	✓60	70	80	90	100
Tuesday AM	10	20	30	40	50	✓60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	✓70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	✓80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	✓90	100
Thursday AM	10	20	30	40	50	60	70	✓80	90	100
Thursday PM	10	20	30	40	50	60	70	80	✓90	100
Friday AM	10	20	30	40	50	✓60	70	80	90	100
Friday PM	10	20	✓30	40	50	60	70	80	90	100

Sample 14

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?
   - ☐ Monday
   - ☐ Tuesday
   - ☐ Wednesday
   - ☑ Thursday
   - ☐ Friday

2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?
   - ☐ Monday
   - ☑ Tuesday
   - ☐ Wednesday
   - ☐ Thursday
   - ☐ Friday

3. Please specify the type of mistake that occurs most often within a working day:
   - ☐ Material is not supplied to the original location of demand as planned
   - ☑ Material Damage due to poor on-site material handling
   - ☐ Incorrect batch sizing of predefined loads of material
   - ☐ Delays on preplanned cycle times of material loads
   - ☐ Any other most common mistake or accident please specify:

   ➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 15

Steven McKerr

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑
3. Please specify the type of mistake that occurs most often within a working day:	
Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☑
Any other most common mistake or accident please specify: →	☐

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

	10	20	30	40	50	60	70	80	90	100
Monday AM				(40)						
Monday PM						(60)				
Tuesday AM						(60)				
Tuesday PM							(70)			
Wednesday AM								(80)		
Wednesday PM									(90)	
Thursday AM							(70)			
Thursday PM								(80)		
Friday AM						(60)				
Friday PM							(70)			

Sample 16

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☑
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

	10	20	30	40	50	60	70	80	90	100
Monday AM					(50)					
Monday PM							(70)			
Tuesday AM							(70)			
Tuesday PM									(90)	
Wednesday AM										(100)
Wednesday PM										(100)
Thursday AM									(90)	
Thursday PM								(80)		
Friday AM						(60)				
Friday PM				(40)						

Sample 17

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify: ➔	☐

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 18

7.11.06

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?
   - ☐ Monday
   - ☐ Tuesday
   - ☐ Wednesday
   - ☐ Thursday
   - ☑ Friday

2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?
   - ☑ Monday
   - ☐ Tuesday
   - ☐ Wednesday
   - ☐ Thursday
   - ☐ Friday

3. Please specify the type of mistake that occurs most often within a working day:
   - ☑ Material is not supplied to the original location of demand as planned
   - ☑ Material Damage due to poor on-site material handling
   - ☑ Incorrect batch sizing of predefined loads of material
   - ☑ Delays on preplanned cycle times of material loads
   - ☐ Any other most common mistake or accident please specify:

   →

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	(40)	50	60	70	80	90	100
Monday PM	10	20	30	(40)	50	60	70	80	90	100
Tuesday AM	10	20	30	40	(50)	60	70	80	90	100
Tuesday PM	10	20	30	40	50	(60)	70	80	90	100
Wednesday AM	10	20	30	40	50	60	(70)	80	90	100
Wednesday PM	10	20	30	40	50	60	70	(80)	90	100
Thursday AM	10	20	30	40	50	60	(70)	80	90	100
Thursday PM	10	20	30	40	50	(60)	70	80	90	100
Friday AM	10	20	30	(40)	50	60	70	80	90	100
Friday PM	10	20	30	(40)	50	60	70	80	90	100

Sample 19

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☑
Any other most common mistake or accident please specify:	☐
➔	

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	**(10)**	20	30	40	50	60	70	80	90	100
Monday PM	10	**(20)**	30	40	50	60	70	80	90	100
Tuesday AM	10	20	**(30)**	40	50	60	70	80	90	100
Tuesday PM	10	20	30	**(40)**	50	60	70	80	90	100
Wednesday AM	10	20	30	40	**(50)**	60	70	80	90	100
Wednesday PM	10	20	30	**(40)**	50	60	70	80	90	100
Thursday AM	10	20	**(30)**	40	50	60	70	80	90	100
Thursday PM	10	**(20)**	30	40	50	60	70	80	90	100
Friday AM	**(10)**	20	30	40	50	60	70	80	90	100
Friday PM	**(10)**	20	30	40	50	60	70	80	90	100

Sample 20

DARREN HOLMES

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☑
	Tuesday	☐
	Wednesday	☑
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☑
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 21

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☑ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☑
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	**80**	90	100
Monday PM	10	20	30	40	50	60	70	**80**	90	100
Tuesday AM	10	20	30	40	50	60	70	**80**	90	100
Tuesday PM	10	20	30	40	50	**60**	70	80	90	100
Wednesday AM	10	20	30	40	50	**60**	70	80	90	100
Wednesday PM	10	20	30	40	**50**	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	**70**	80	90	100
Thursday PM	10	20	30	40	50	60	70	**80**	90	100
Friday AM	10	20	30	40	**50**	60	70	80	90	100
Friday PM	10	20	**30**	40	50	60	70	80	90	100

Sample 22

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☑ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☐
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☑
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 23

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☑
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	■	70	80	90	100
Monday PM	10	20	30	40	50	60	■	80	90	100
Tuesday AM	10	20	30	40	50	60	70	■	90	100
Tuesday PM	10	20	30	40	50	60	70	■	90	100
Wednesday AM	10	20	30	40	50	60	■	80	90	100
Wednesday PM	10	20	30	40	50	60	70	■	90	100
Thursday AM	10	20	30	40	50	60	■	80	90	100
Thursday PM	10	20	30	40	50	■	70	80	90	100
Friday AM	10	20	30	40	50	■	70	80	90	100
Friday PM	10	20	30	40	■	60	70	80	90	100

Sample 24

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☑
Material Damage due to poor on-site material handling	☑
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

→

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 25

The objective of this questioner is to identify the causes for variation in the daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑

3. Please specify the type of mistake that occurs most often within a working day:

Material is not supplied to the original location of demand as planned	☐
Material Damage due to poor on-site material handling	☑
Incorrect batch sizing of predefined loads of material	☐
Delays on preplanned cycle times of material loads	☐
Any other most common mistake or accident please specify:	☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	10	20	30	40	50	60	70	80	90	100
Monday PM	10	20	30	40	50	60	70	80	90	100
Tuesday AM	10	20	30	40	50	60	70	80	90	100
Tuesday PM	10	20	30	40	50	60	70	80	90	100
Wednesday AM	10	20	30	40	50	60	70	80	90	100
Wednesday PM	10	20	30	40	50	60	70	80	90	100
Thursday AM	10	20	30	40	50	60	70	80	90	100
Thursday PM	10	20	30	40	50	60	70	80	90	100
Friday AM	10	20	30	40	50	60	70	80	90	100
Friday PM	10	20	30	40	50	60	70	80	90	100

Sample 26

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	5	10	15	20	25	(30)	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Monday PM	5	10	15	20	25	30	35	(40)	45	50	55	60	65	70	75	80	85	90	95	100
Tuesday AM	5	10	15	20	25	30	35	40	45	(50)	55	60	65	70	75	80	85	90	95	100
Tuesday PM	5	10	15	20	25	30	35	40	45	(50)	55	60	65	70	75	80	85	90	95	100
Wednesday AM	5	10	15	20	25	30	35	40	45	50	55	(60)	65	70	75	80	85	90	95	100
Wednesday PM	5	10	15	20	25	30	35	(40)	45	50	55	60	65	70	75	80	85	90	95	100
Thursday AM	5	10	15	20	25	30	35	40	45	(50)	55	60	65	70	75	80	85	90	95	100
Thursday PM	5	10	15	20	25	30	35	40	45	(50)	55	60	65	70	75	80	85	90	95	100
Friday AM	5	10	15	20	25	(30)	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Friday PM	5	10	15	(20)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100

Sample 27

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☐
	Wednesday	☐
	Thursday	☐
	Friday	☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday	☐
	Tuesday	☑
	Wednesday	☐
	Thursday	☐
	Friday	☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☐
- Material Damage due to poor on-site material handling ☑
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	

Sample 28

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☑ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	

Sample 29

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Monday PM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday AM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday PM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday AM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday PM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday AM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday PM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday AM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday PM	0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Sample 30

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☐ ☐ ☑
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☐ ☑ ☐ ☐

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	
Monday PM	
Tuesday AM	
Tuesday PM	
Wednesday AM	
Wednesday PM	
Thursday AM	
Thursday PM	
Friday AM	
Friday PM	

Sample 31

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☑ ☐ ☐ ☐ ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday Tuesday Wednesday Thursday Friday	☐ ☑ ☐ ☐ ☐

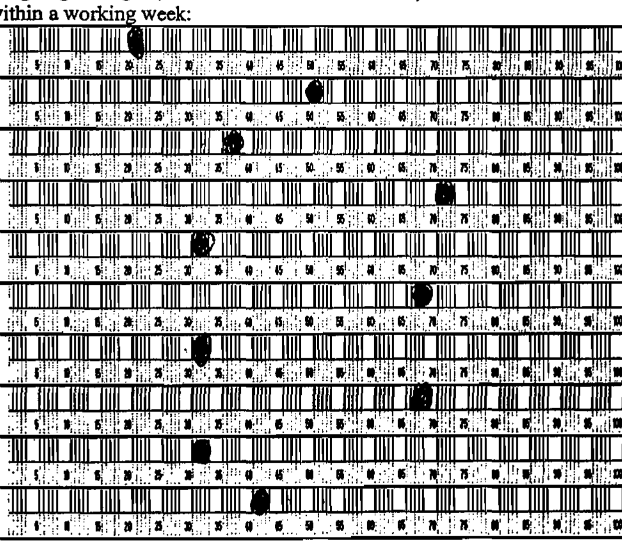
3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned ☑
- Material Damage due to poor on-site material handling ☐
- Incorrect batch sizing of predefined loads of material ☐
- Delays on preplanned cycle times of material loads ☐
- Any other most common mistake or accident please specify: ☐

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM
Monday PM
Tuesday AM
Tuesday PM
Wednesday AM
Wednesday PM
Thursday AM
Thursday PM
Friday AM
Friday PM



Sample 32

Daily performance variation questioner

The objective of this questioner is to quantify variation in daily work performance and to assign a proportional weight to buffer the identified daily variation. This is done by integrating these weights into the planning of the daily workloads at construction sites. Kindly answer the questions in respect to the specified objective.

1. Which specific day within a working week shows the highest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☑ Thursday ☐ Friday ☐
2. Which specific day within a working week shows the lowest number of mistakes or accidents caused by construction workers?	Monday ☐ Tuesday ☐ Wednesday ☐ Thursday ☐ Friday ☑

3. Please specify the type of mistake that occurs most often within a working day:

- Material is not supplied to the original location of demand as planned [3]
- Material Damage due to poor on-site material handling [1]
- Incorrect batch sizing of predefined loads of material [2]
- Delays on preplanned cycle times of material loads [4]
- Any other most common mistake or accident please specify: [5]

➔

4. If a working day is divided into two shifts (AM and PM) categorize the daily workload by assigning a weight (on a scale between 0%-100%) to each shift of each working day within a working week:

Monday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Monday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Tuesday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Wednesday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Thursday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday AM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Friday PM	5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

Feedback e-mail Prof. Dr. Randolph Thomas

Basil Al-Sasi

From: "HR Thomas" <hrt1@psu.edu>
To: "Basil Al-Sasi" <boas@soton.ac.uk>
Sent: 08 September 2006 15:32
Subject: Re: PhD student Basil Al-Sasi University of Southampton UK

Dear Basil:

Thank you for your e-mail. First, you should know that I am not a proponent or a believer in lean construction. Their writings are often vague and hard to know how to put into practice. Therefore, I view much of what is said as just talk. They have no data. There are some good things they say, but overall, muck of what they say is whooie. I could say more, but let's just leave it at that.

Regarding measurements, I find the baseline productivity to be the only thing that is consistent internationally. Some of my papers detail this, and I wrote a CIB (report #276) which you should review. The Project Waste Index seems to be a good measure of performance. A value of 0.5 is about an average project.

If you haveany other questions, please let me know. Meanwhile, you may wish to contact Dr. R. W. Malcolm Horner at Dundee. He is a good contact.

At 02:35 PM 9/7/2006 +0100, you wrote:

>Dear Prof. Thomas,<?xml:namespace prefix = o ns =
>"urn:schemas-microsoft-com:office:office" />
>
>
>
>I am a PhD student at the <?xml:namespace prefix = st1 ns =
>"urn:schemas-microsoft-com:office:smarttags" />University of Southampton
>in the United Kingdom. I have read many of your papers and I like your
>thoughts on lean construction and the suggested techniques for measuring
>the performance of construction workers. I participated in the 14th IGLC
>2006 conference which was held in Santiago Chile. Since I am interested in
>your work I thought it would be a good idea to e-mail you a copy of my
>paper so that you could give me some feedback.
>
><http://www.iglc2006.cl/papers.html#72>http://www.iglc2006.cl/papers.html#72
>
>
>
>Kind Regards,
>
>
>
>Basil Al-Sasi

Figure F 1: Feedback e-mail received from Prof. Randolph Thomas