LEAN CONSTRUCTION

Should Lean Construction be part of a construction company's objective in South Africa?

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Should Lean Construction be part of a construction company's objective in South Africa?

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Declaration by student

I, the undersigned, hereby confirm that the attached treatise is my own work and that any sources are adequately acknowledged in the text and listed in the bibliography.

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Signature of acceptance and confirmation by student

Abstract

Title of treatise :	Lean Construction- Should Lean Construction be part of a construction company's objective?
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The construction industry in South Africa is not perfect and there are all kinds of chronic problems like for example low productivity, poor safety, inferior working conditions, waste and insufficient quality, and evaluation of the performance at site- and project level. These problems also exist in other countries around the world. In some of these countries (like Japan, America and some European countries) they developed a new production philosophy, called lean construction, which was developed to solve these problems.

The objective of this treatise is to investigate this process called Lean construction to see what it is; how it is implemented; how its performance can be measured; and what tools are used to execute lean construction in a construction company. The sole point of this investigation will be to show that this new form of production management should become part of a construction company's objective, aim and goal in South Africa and will not only help these companies to solve chronic problems in a construction company itself but also on the different sites of the construction company. This will not only apply for Construction companies in South Africa but also for construction companies around the world.

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1.1 Brief overview

Some of the chronic problems of construction are for example low productivity, poor safety, inferior working conditions, waste and insufficient quality, and the evaluation of the performance at site- and project level. There are a number of ways to relieve these problems in construction, for example, industrialization (prefabrication and modularization), computer integrated construction, and the vision of robotized and automated construction. Some of these solutions come directly from the manufacturing industry, for example, the idea of industrialization and the computer integration and automation.

At this time, there is a different development trend in manufacturing, the impact of which appears to be much greater than that of information and automation technology. This trend is based on a new production philosophy, rather than on new technology, and stresses the importance of basic theories and principles related to production processes. This new production philosophy is called Lean Construction.

Lean construction is a new concept introduced into the construction industry. It has been practiced in other countries for a couple of years but has not entirely found its feet in the construction industry in South Africa.

Lean construction is a different method to make a difference not only in the construction industry but also in the world. Lean construction is not only a way to reform the way work on projects is performed but it is also ***"a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value"*** (Koskela et al. 2002).

Research will be done on lean construction to see how new this concept is; what lean construction is; how lean construction can be monitored and measured; how lean construction will be implemented in a construction company; and what tools and methods are used in the incorporation of lean construction.

1.2 The main problem

The construction industry in South Africa and in other countries around the world contains certain problems- low productivity, insufficient quality, waste (internal and external to the company), and inferior working conditions. A new concept or production philosophy, called lean construction or lean production, has been developed to resolve these problems that exist in the construction industry and in construction companies. It has not quite made its mark in the construction industry or construction companies in South Africa. The main problem can be stated as follows: **Should lean construction become part of a construction company's objective in South Africa?**

1.3 The sub problems

The following sub problems will be investigated in order to come to a final conclusion:

1.3.1 What is lean construction and is it a new concept?

1.3.2 How will the performance of lean construction be measured in a construction company?

1.3.3 How will lean construction be implemented in a construction company?

1.3.4 What tools and methods are used to support lean construction?

1.4 The hypothesis

Sub problem 1:

- Lean construction is a way work is done to meet customer needs while using less of everything. It comprises of a new project delivery system that will be suited for any kind of construction project. Lean construction will minimize waste on construction sites. Lean construction is a new concept though it has been around for a couple of years, but has not been implemented or fully been implemented in certain countries, South Africa being one of these countries.

Sub problem 2:

- Lean construction has specific performance elements which management should focus on (effectiveness, quality, profitability, innovation, etc). The traditional models of project performance are in many ways obstacles to improving construction productivity and offer only a limited set of measures, however it can be used together with the new model to predict and measure performance at the site and project level. Lean construction will thus improve construction performance by using old concepts and implementing new approaches to them.

Sub problem 3:

- Lean construction can mainly be implemented by reducing the inflow variation, stabilizing work flow, and improving downstream performance. These three implementation strategies need to be incorporated together, because they depend on the results of one another.

Sub problem 4:

- When developing tools for lean construction, there are certain principles that need to be considered. There are two categories for the tools that support lean construction: (1) tools that support reengineering business processes, and (2) tools that support planning and controlling business processes. The first tool (reengineering business processes) that can be used in lean construction contains two methods: (1) activity and cost analyses, and (2) accuracy and delivery time analyses. The second tool (planning and controlling business processes) that can be used in lean construction is a PC-based software, called TOIMI.

1.5 Delimitations

The research conducted in this treatise is based on the construction industry worldwide and has no further limits or delimitations.

1.6 Assumptions

No assumptions have been made while compiling this treatise.

1.7 Importance of the study

By understanding what lean construction is and what it entails can help construction companies in the South African construction industry to realize that there is a need to change their company's objectives, goals, aims, visions and philosophy towards this new philosophy. Lean construction will help them to become a more efficient, sophisticated construction company who cares about how they do business and the impression they leave with their clients.

Once a construction company understands what lean construction is and start to implement it in their management, they will immediately see a change which is beneficial towards the company and it will not only improve the company itself but will also change the way business is done in the whole of the construction industry.

1.8 Research methodology

The treatise is based on information obtained from the following sources:

1.8.1 Various textbooks on lean construction;

1.8.2 Scientific journals obtained from the UP library on the subject;

1.8.3 Electronic articles published on the Internet on the subject.

Chapter two

What is lean construction and is it a new concept?

2.1 Introduction

A few well-known problems in the construction industry are poor safety, low productivity, insufficient quality, waste, and inferior working conditions. With manufacturing as a reference point and a source of innovation a number of solutions and visions have been offered to reduce these problems in the construction industry, for example industrialization, computer integrated construction along with robotized and automated construction.

Another development trend in manufacturing is based on a new production philosophy, rather than on a new technology, which stresses the importance of basic theories and principles related to the production process. This new production philosophy is called **Lean construction/Lean production** and like current practice the aim is to meet client needs while using less of everything. Lean construction differs from current practice in the sense that it rests on production management principles, meaning the "physics" of construction. The result will be to provide a new project delivery system that can be used on any type of construction but is mainly suited for uncertain, difficult, and fast track projects.

2.2 Historical overview of lean production

Lean production was developed by Toyota, led by an Engineer called Ohno. He was a smart, sometimes difficult, person dedicated to eliminating waste. The term "lean" was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production (Womack et al. 1991). Ohno wanted to build cars to client order and not like Henry Ford who focused on an unlimited demand for a standard product. Efforts from reduce machine set up time to total quality management helped Ohno to develop a simple set of objectives for the design of the production system: manufacture a car to the necessities of a specific client, deliver it instantly, with no inventory maintenance.

Waste is defined by the performance criteria for the production system. Failure to meet the unique requirements of a client is waste, as is time beyond instant and inventory standing idle (Howell, 1999). So to minimize waste Ohno had to shift his improvement focus from the activity to the delivery system.

Ohno and his team of engineers were familiar with mass production of cars from their visits to the United States of America. He was not quite impressed with the method they used, because where the US managers saw efficiency, he saw waste. Ohno understood that ***"the pressure to keep each machine running at maximum production led to extensive intermediate inventories in other words waste of over production"*** (Howell, 1999). Defects were built into cars just to keep the assembly line moving. The US tried to minimize the cost of each part and car by keeping the machines running and the line moving. Ohno created a system design criteria that prevented sub-optimization and promoted continuous improvement, which set a multi-dimensioned standard of perfection. This means that to meet customer requirements, in zero delivery time, with nothing in the inventory required tight coordination between the movement of each car down the line and the arrival of parts from the supply chains. Rework due to errors was not tolerated- it increased the time to manufacture a car from beginning to end and it also caused unreliable workflow. If workflow is unreliable the coordination of the arrival of parts would be impossible. Ohno even instructed the workers to stop the line if there were any defective parts or products coming from the upstream, because he recognized that reducing the cost or increasing the speed could add further waste if variability was injected into the flow of work by the "improvement" (Howell, 1999).

He created an inventory control strategy, which was developed to replace the central push with a distributed pull. The pull helped to reduce work in progress, which in turn tied up less working capital and decreased the cost of design changes during manufacture.

"Ohno also decentralized shop floor management by making visible production system information to everyone involved with production. "Transparency" allowed people to make decisions in support of production system objectives and reduced the need for more senior and central management" (Howell, 1999).

According to Howell (1999) ***"As Ohno came to better understand the demands of low waste production in manufacturing, he moved back into the design process and out along supply chains. In an effort to reduce the time to design and deliver a new model, the design of the production process was carefully considered along with the design of the car. Engineering components to meet design and production criteria was shifted to the suppliers. New commercial contracts were developed which gave the suppliers the incentive to continually reduce both the cost of their components and to participate in the overall improvement of the product and delivery process. Toyota was a demanding customer but it offered suppliers continuing support for improvement".***

Lean production will always develop and change but the basic outline will most of the time remain clear. The production system must be able to deliver a custom product instantly on order but maintain no intermediate inventories.

Thus, lean production (new production philosophy) is emerging and has been practiced or partially practiced by major manufacturing companies in America, Europe and Japan (Koskela, 1993).

2.3 Conceptual framework of lean production

According to Howell (1999) ***"the basic concepts of lean production are":***

- ***Identify and deliver value to the customer value: eliminate everything that does not add value.***
- ***Organize production as a continuous flow.***
- ***Perfect the product and create reliable flow through stopping the line, pulling inventory, and distributing information and decision-making.***
- ***Pursue perfection: Deliver on order a product meeting customer requirements with nothing in inventory.***

Koskela (1993) went and did a deeper study and explained that "***The core concept of the new production philosophy is in the observation that there are two aspects in all production systems: <u>Conversions</u> and <u>flows</u>. While all activities expend cost and consume time, only conversion activities add value to the material or piece of information being transformed into a product. Thus, the improvement of non value adding flow activities (inspection, waiting, moving), through which the conversion activities are bound together, should primarily be focused on reducing or eliminating them, whereas conversion activities should be made more efficient. In design, control and improvement of production systems, both aspects have to be considered. Traditional managerial principles have considered only conversions, or all activities have been treated as though they were value-adding conversions. Due to these traditional managerial principles, flow processes have not been controlled or improved in an orderly fashion.***

We have been preoccupied with conversion activities. This has led to complex, uncertain and confused flow processes, expansion of non-value adding activities, and reduction of output value. Material and information flows are thus the basic unit of analysis in the new production philosophy. Flows are characterized by time, cost and value".

Thus, if flow processes were not so important in the past this would mean that there would be a considerable amount of waste (non-value-adding activities) in current construction. According to Koskela (1993) "***there has never been any systematic attempt to observe all wastes in a construction process. However, partial studies from various countries can be used to indicate the order or magnitude of non-value adding activities in construction. The compilation presented in Table 1 indicates that a considerable amount of waste exists in construction. However, because conventional measures do not address it, this is invisible in total terms, and is considered to be un-actionable".***

Waste	**Cost**	**Country**
Quality costs (non-conformance)	12% of total project costs	USA
External quality cost (during facility use)	4% of total project costs	SWEDEN
Lack of constructability	6–10% of total project cost	USA
Poor materials management	10–12% of labor costs	USA
Excess consumption of materials on site	10% on average	SWEDEN
Working time used for non-value adding activities on site	Appr. 2/3 of total time	USA
Lack of safety	6% of total project costs	USA

Table 1- Waste in construction: Compilation of existing data (Koskela, 1993).

2.4 Principles of lean production

There have been a number of principles that have evolved over the years in the flow process. Sufficient evidence shows that the following principles will significantly and rapidly improve the efficiency of flow processes, as explained by Koskela (1993) they are:

- ***"Reduce the share of non value adding activities, also known as waste;***
- ***Increase output value through systematic consideration of customer requirements;***
- ***Reduce variability;***
- ***Reduce cycle times;***
- ***Simplify by minimizing the number of steps, parts, and linkages;***
- ***Increase output flexibility;***
- ***Increase process transparency;***
- ***Focus control on the complete process;***
- ***Build continuous improvement into the process;***
- ***Balance flow improvement with conversion improvement;***
- ***Benchmark";***

These principles in general apply to both the total flow processes and to its sub-processes. They also define the flow process problems: complexity, lack of transparency, and segmented control. Research shows that these principles are universal and apply to almost any production process for example physical production, informational production (design), mass production, and one-of-a-kind production (Koskela, 1993).

2.5 Instruments used in lean production

Lean production is a combination of existing principles of management techniques. These principles together try to avoid the waste of time, money, equipment, etc. By simulating all the employees, the main focus can be on productivity improvement and cost reduction. In other words, "*let everybody* *manage their own problems and don't create new problems by managing the problems of somebody else*" (Melles 1994)! Lean production was developed in Japan. There is a wide spectrum of techniques used in lean production but the most important instruments used in lean production are defined by Melles (1994) as:

- ***Multifunctional task groups***

"Many authors agreed that the instrument of multifunctional task-groups is one of the most important instruments of lean production. Instead of homogeneous task groups a multifunctional task group produces a number of different products. This makes it possible to produce a more complex or more completed product with one production unit. It transfers the maximum number of tasks and responsibilities to those workers actually adding value. In the meantime an accurate response to market developments can be achieved by flexible deployment of personnel (Womack et al. 1990). In multifunctional task groups workers do not have to wait for each other. It also does not give stocks. To achieve the principle of multifunctional task groups, personnel have to be trained intensively in recombining thinking and doing (Kenward 1992)".

- ***Simultaneous engineering***

"Today technology changes rapidly. This reduces the lifecycle of products. For this reason a reduction of product development time is essential. Simultaneous engineering can achieve this. By using simultaneous engineering the design and manufacture of the product is no longer separated, physically and time-wise, but integrated and synchronized, through face to face co-operation between designers and producers in a product development team. Direct communication and co-operation can reduce the development period of products significantly (factor 2 to 3). Simultaneous engineering reduces muda by avoiding miscommunication between engineering and production.

Within simultaneous engineering also market research is incorporated. This reduces the development of products which are not liked by the clients".

- ***Kaizen***

"Kaizen is Japanese for permanent and stepwise quality improvement. Kaizen stimulates personnel at all levels in a company to use their brains to reduce costs. In fact Kaizen requires permanent new ideas for cost reduction. In some cases this implicates a strict demand from the management to all production units to create a new idea each week. A good implementation of Kaizen implicates cost reduction and zero defects in final products. It is obvious that Kaizen reduces muda (Imai 1993). Kaizen demands employee involvement".

- ***Just-in-time deliveries***

"Just-in-time is a concept for good-flow control. It stimulates reduction of stocks of material by providing goods when and in the amounts needed (Ohno & Mito 1988). Traditional good-flow oriented control concepts are managing the stock. Instead, primarily short-term decisions are made based upon the current demand for products. New subassemblies are made only immediately before they are actually needed. The ultimate result is that only extremely small subassembly inventories are needed. Traditional inventory control is based upon detailed scheduling techniques (demand for parts is 'pushed'). With JIT, the actual production of new subassemblies is initiated based upon the demand for products which are really needed (the 'pull' approach). Transparent production control (visual management) is important. Stock of materials is seen as muda. The implementation of JIT needs reliable production (zero defects) and good (and steady) relations with suppliers".

- ***Long term relationships with suppliers (co-makership)***

"The basic idea of co-makership is to create co-operation with your suppliers (Womack et al. 1990). This means e.g.:

– Mutual technology transfer;

– Mutual openness;

– Mutual management support;

– Mutual declining of stock;

– Mutual sharing of profits.

Long term relationship with suppliers stimulates a relation which is founded on cooperation instead of conflicts. Disturbances in relations cause muda".

- ***Customer orientation***

"The entire company must be focused on the client (Womack et al. 1990), internal as well as external client-supplier relations are very important. Good communication with your client declines problems. As a result this declines muda".

- ***Information, communication and process structure***

"Lean production demands a transparent organization (Koeleman 1991). A transparent and flat organization implicates better information and communication, internal as well as external. A simple organization structure makes it easier to communicate. A transparent organization makes is easier to have an overview of consequences of control actions. It is obvious that bad communication declines muda".

2.6 Lean construction (also known as lean production in construction)

Lean construction accepts Ohno's production system criteria, but how will this apply in the construction industry? Many ideas have been rejected from manufacturing, not only because the construction industry is different but also because the construction industry is unique, very complex, has highly uncertain environments, and there is a lot of pressure to time and scheduling.

As in manufacturing, the goal of delivering a project in a limited time, minimizing waste, and at the same time meeting the specific requirements of the client sounds like the objective of every construction project. According to Howell (1999) ***"waste in construction and manufacturing arises from the same activity-centered thinking, keep intense pressure for production on every activity because reducing the cost and duration of each step is the key to improvement".*** There are improved ways to design and make things, and Ohno knew and saw it.

Howell (1999:4) said that ***"managing construction under Lean is different from typical contemporary practice because it"***:

- ***Has a clear set of objectives for the delivery process,***
- ***Is aimed at maximizing performance for the customer at the project level,***
- ***Designs concurrently product and process, and***
- ***Applies production control throughout the life of the project.***

Further research is done by Koskela and he found that there are barriers to the implementation of the new philosophy in construction. Koskela (1992a) found that ***"the most important barriers to the implementation of this idea in construction seem to be"***:

- ***Cases and concepts commonly presented to teach about and diffuse the new approach have often been specific to certain types of manufacturing, and thus not easy to internalize and generalize from the point of view of construction;***
- ***Relative lack of international competition in construction;***
- ***Lagging response by academic institutions.***

These barriers that are listed above are only of a temporary nature and they can be overcome in time.

The existing form of production management in construction is resultant from the same activity centred approach found in mass production and project management. So, by assuming that customer value has been identified in the design stage it aims to optimize the project activity by activity. The project is first broken into pieces, design and construction, then these pieces are assembled in a logical sequence and their time and resources are estimated to complete each of the activities and by adding all of them together to the project. Each activity is then further decomposed until it is assigned to a task leader, foreman, or squad boss. They then control the activities and monitor each activity against its schedule and budget projections. Projections must be reported to the project level. If any of the critical activities (activities on the critical path) are late or behind, efforts must be made to reduce the cost and duration of the activity that is behind or the sequence of work must be changed. Sometimes it is necessary to trade cost for schedule to work out the best sequence to make progress. The problem with this method is that the focus on activities conceals the waste that is generated between the continuing activities due to the unpredictable release of work and the arrival of resources that are needed at a specific time. Thus, current forms of production and project management focus too much on the activities and less on flow and value considerations (Howell 1999, Koskela 1992 and Huovila 1997).

The first concern in lean production is managing the combined effect of dependence and variation and should also be the first goal of lean construction. By managing the combined effect of dependence and variation between activities is essential in order to finish projects in the shortest time. As project duration is reduced and the complexity increased, the critical issue for the planning and control system will be the minimization of the combined effects of dependence and variation. Thus, lean construction must fully understand the “physics” of production and the effects of dependence and variation along the supply chains. In current practice we ignore the physical issue and focus more on teamwork, communication and commercial contacts.

Lean construction supports the development of teamwork along supply chains and also shifting the burdens along the supply chain. This means that while partnering (where representatives of each activity communicates directly without relying on the central authority to control the message flow) focuses on building trust, lean is about building reliability. Lean construction also differs from physical production in the sense that lean tries to isolate the different teams from variation in the supply chain by providing a backlog or maintaining excess capacity in the team, thereby enabling speeding up or slowing down as the situation dictates.

People in current practice say that they are helpless victims of fate when faced with managing uncertainty on their projects and that uncertainty comes in other activities that are beyond their control. But according to Howell (1999) ***“Lean construction embraces uncertainty in supply and use rates as the first great opportunity and employs production planning to make the release of work to the next crew more predictable, working within the crews to understand the cause of variation. The lean***

approach assures that no contribution is made to variation in work flow and to decouple when unable to control. Planning and control are two sides of a coin that keeps evolving throughout a project. Where current practice attacks point speed, lean construction attacks variation system wide".

In construction the administrative act, planning, releases work. So the key to improving workflow reliability is based on improving and measuring the planning system performance. This reflects the understanding of cause and effect, but this is for another novel.

2.7 Comparison between conventional- and lean production

Koskela (1993) summarizes in the table 2 below the most important differences between conventional- and lean production:

	Conventional production philosophy	**New production philosophy**
Conceptualization of production	Production consists of conversions (activities); all activities are value-adding	Production consists of conversions and flows; there are value-adding and non-value-adding activities
Focus of control	Cost of activities	Cost, time, and value of flows
Focus of improvement	Increase of efficiency by implementing new technology	Elimination or suppression of non-value adding activities, increase of efficiency of value adding activities through continuous improvement and new technology

Table 2- The conventional and the new production philosophy (Koskela 1993).

Koskela (1993) schematically illustrates in Figure 1 the results of implementing the conventional- and new production philosophy:

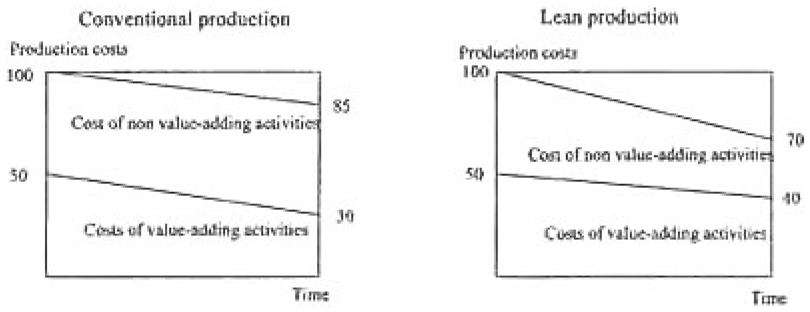

Figure 1- Conventional and lean production: Focus of development efforts (Koskela 1993).

From the above it can be seen that conventional production is improved by implementing new technology in not only value adding activities but also to some extent in non-value adding activities. Lean production tries to attend to non-value adding activities, because with time the cost of non-value activities, which are not controlled, tend to grow. Thus, production becomes more complex and prone to disturbances. Costs of non-value adding activities can be reduced by measurements and applying the principles for flow control. Value adding activities are internally improved and through fine-tuning of existing plant/machinery. Koskela (1993) says that ***"the implementation of new technology is easier in lean production, because fewer investments are needed and the production is better controlled. Thus, after the initial phase, increase of efficiency of value adding activities should also be more rapid in lean production than in conventional production".***

2.8 Conclusion

In conclusion, lean construction is a new form of production management that originated from the conventional production system in manufacturing (Japan). Lean construction is a new production philosophy which stresses the importance of basic theories and principles in the production system and aims to meet client requirements while using less of everything. Lean construction is suited to any kind of construction project, but mainly for uncertain, complex and fast track projects. As can be seen in table 1 above, waste does exist in construction companies and lean construction will reduce this waste if the appropriate measures are taken and the new philosophy implemented.

As highlighted by Howell (1999) the basic concepts of lean production are clear. Koskela (1993:2) did a deeper study and explained that "***The core concept of the new production philosophy is in the observation that there are two aspects in all production systems: <u>Conversions</u> and <u>flows</u>.*** There are also different instruments (Multifunctional task groups, Simultaneous engineering, Kaizen, Just-in-time deliveries, Long term relationships with suppliers (co-makership), Customer orientation, Information, communication and process structure) that can be used in lean production as explained by Melles (1994).

Lean construction is different in some ways from lean manufacturing but they both have the same goal which is the delivery of a project in a limited time, minimizing waste, and at the same time meeting the specific requirements of the client. Barriers do exist but they are of a temporary nature and can be overcome in time. Lean construction supports the development of teamwork along supply chains and also shifting the burdens along the supply chain. This means that lean construction not only focuses on building trust, but also on building reliability.

From table 2 and figure 1 it can be seen that the conventional production philosophy and the new production philosophy shares some principles but the new production is more improved in some ways. Basic principles are modified.

Some of the essential features of lean construction include: a clear set of objectives for the delivery process, meeting specific customer/client requirements at the project level, designing of products and processes at the same time, and production control of the product from the beginning (design phase) to the end (delivery phase).

2.9 Testing of hypothesis

The hypothesis stated in chapter one stated:

"Lean construction is a way how work is done to meet customer needs while using less of everything. It comprises of a new project delivery system that will be suited for any kind of construction project. Lean construction will minimize waste on construction sites. Lean construction is a new concept though it has been around for a couple of years, but has not been implemented or fully been implemented in certain countries, South Africa being one of these countries".

In testing this hypothesis, it can be said that the hypothesis was partially correct as lean construction has been around for a couple of years. It is still a new concept in certain countries but in theory it has been around for a few years. Countries like Japan, America and certain European countries use the new production theory. It has not been fully practiced or implemented in certain countries, including South Africa, and thus making it "new" for them. The hypothesis was also partially correct regarding the nature of lean construction. It is more than just using less of everything, but in the end it will reduce waste on construction sites.

Chapter three

How will the performance of lean construction be measured in a construction company?

3.1 Introduction

Over the years it has been a challenge in the construction industry to evaluate the performance at site- and project level. Most of these models and procedures that have been developed to evaluate performance of a project focus on either the prediction of project performance or on measuring. Some of them limit their analysis to measures such as cost, schedule, or productivity (mostly labour).

According to Koskela (1992) ***"the application of new production philosophies in construction requires the evaluation of new measurements such as waste, value, cycle time or variability".*** These elements are defined by Koskela (1992) as:

- ***"Waste:*** *Number of defects, rework, number of design errors and omissions, number of change orders, safety costs, excess consumption of materials, etc.;*
- ***Value:*** *Value of the output to the internal customer;*
- ***Cycle time:*** *Cycle time of main processes and sub processes;*
- ***Variability:*** *Deviations from the target, such as schedule performance".*

This means that the conventional/traditional model is not appropriate in measuring such performance elements. But, old concepts with the implementation of new approaches to construction performance improvement can be applied to measure those elements.

The problem with performance evaluation is the fact that it is a multi-criteria one. Individual measures will not be equally weighted by two managers or organizations and they will probably also not use the same performance measures. Thus, the new model must not have the flexibility to include individual organizational objectives in the evaluation process but also the ability to examine the effect of changes in those objectives.

3.2 Elements of performance

The word ‘performance’ entails all characteristics of the construction process, from on-site activities (productivity, safety, timeliness, and quality) to off-site. Sink (1985) characterized performance in seven elements (effectiveness, efficiency, quality, profitability, innovation, quality of work life, and productivity), which management should focus on. Sink (1985) defined them as:

1. ***Effectiveness:*** *“A measure of accomplishment of the ‘right’ things: a) on time (timeliness), b) Right (quality), c) All the ‘right’ things (quantity). Where ‘things’ are goals, objectives, activities and so forth”;*
2. ***Efficiency:*** *“A measure of utilization of resources. It can be represented as the ratio of resources expected to be consumed divided by the resources actually consumed”;*
3. ***Quality:*** *“A measure of conformance to specifications. In construction projects, quality has two dimensions: The first and overall one is that of the completed project functioning as the owner intended; the second concerns the many details involved in producing this result”;*
4. ***Productivity:*** *“Theoretically this is defined as a ratio between output and input. According to the Bureau of Labour Statistics, a measure of*

productivity is more specifically an expression of the physical or real volume of goods and services (output) related to the physical or real quantities of input (e.g. labour, capital and energy). In the context of the construction industry, the output is the structure or facility that is built or some component thereof. The major input into the construction process includes workforce, materials, equipment, management, energy and capital. Labour productivity is also a measure of efficiency but, because of the labour intensive nature of construction, it is treated as a separate dimension. Productivity is primarily measured in terms of cost";

5. ***Quality of work life:** "A measure of employees' effective response to working and living in organizational systems. Often, the management focus is on ensuring that employees are 'satisfied', safe, secure and so forth";*
6. ***Innovation:** "This is the creative process of adaptation of product, service, process or structure in response to internal as well as external pressures, demands, changes, needs and so forth";*
7. ***Profitability:** "This is a measure or a set of measures of the relationships between financial resources and uses for those financial resources. For example, revenues/costs, return on assets and return on investments".*

These definitions are examples of elements that should be used to describe performance. In the construction industry only some of these elements are used to measure performance which only reflects a partial picture. They usually are profitability and productivity, which are necessary conditions for the survival in the construction industry but not sufficient.

3.3 Current performance models

In the following sections we will see some of the current models and methods, and their capabilities, used in research to try and explain the different aspects of project performance. They are measurement models, productivity prediction models, productivity theory factor models, conceptual construction theory models, and causal models.

3.3.1 Measurement models

A Business Roundtable Report (BRA 1982) showed that there are no reasonable measures of aggregate construction productivity available and that new indexes and data collection procedures should be developed. Listed hereunder are some of the main measurement models used today:

- ***Kellogg et al. (1981)*** *proposed a "holistic model, called the <u>hierarchy model of construction productivity</u>, that could be the basis of a cognitive plan to solve the problems of pulling together all the diverse elements of the construction industry and permit the 'total study' of total factor productivity of the industry".* ***Alarcon (1993)*** *explains that "this model defines and measures the factors and elements that influence construction productivity at each level of the construction process; but the broad scope and simplistic form limit its application as a site model for construction productivity. On the other hand, there is a need for greater use of site productivity measurement systems that may allow owners and contractors to monitor and improve productivity".*
- ***Thomas & Kramer (1988)*** *have studied "several procedures to measure productivity on site and have developed <u>recommendations</u> to use effectively these procedures to monitor and improve productivity".*
- ***Tucker et al. (1986)*** *"have implemented a Petrochemical Model Plant database to be used as a baseline measurement of productivity for the industry. In the future, periodic updates of the database would help assess the impacts of different actions on productivity".*

- Work study-based models
- Delay models using stop watch techniques. This model records productive time and delays that takes place during the day.
- Activity models using work sampling techniques. This model categorizes all the activities which were observed into productive, supportive, or idle times.

Thomas (1990) has questioned the validity of some of these models that measure construction productivity, because there were difficulties found in the supporting assumptions which linked their result to construction productivity.

3.3.2 Productivity prediction models

Over the years research has shown that there is no standard method for predicting productivity of construction work. However, there are estimating manuals that provide guidance to account for different conditions. Some of these methods that are used are:

- ***Use data from existing similar work in one area and assume it is directly applicable to a project in a new area.***
- ***Some use a 'gut feel' factor based on an expert's judgment.***

Main variables to determine productivity according to Alarcon (1993) are:

- ***"Number of direct minutes available per hour",***
- ***"The characteristics of worker population" ,***
- ***"And the rate of work during direct work times".***

There is also information available on the effects of different factors on labour productivity (Dallavia 1952; Edmonson 1974; Neil 1982; Neil & Knack 1984).

They included a proposal to use factors like design, labour, availability, location, and the weather. Then there are mathematical analysis techniques that can be used like tables, graphs, and judgment in some cases where the necessary corrections are made to the initial productivity to calculate the predicted value. Adjustment factors based on similar models have been developed by other authors (Brauer 1984; Lorenzoni 1978; Riordan 1986; CORPS 1979).

3.3.3 Productivity theory factor model

The factor model predicts the average productivity during short periods when there is a particular set of conditions. Thomas & Yiakounis (1987) said ***"the work of a crew is affected by many factors that may lead to random and systematic disturbances to performance".*** Alarcon (1993) explains in more depth how this Theory Factor model works*:* **"The cumulative effect of these disturbances is an actual productivity curve that may be irregularly shaped and difficult to interpret. However, if these disturbances can be mathematically discounted from the actual productivity curve, one is left with an ideal productivity curve (Fig. 2). This curve is a smooth one consisting of a basic performance allowance, plus a component resulting from improvements in repetitive operations. The shape and magnitude of the ideal productivity curve is a function of a number of factors that reflect the site environment, construction methods and constructability aspects. Based upon design requirements and construction practices, it is theorized that this curve can be established prior to commencing the work. If cause-effect relationships are known, then actual productivity can be predicted as a function of the number of units produced or as a function of time. The model contains systematic, random and time-dependent variables"**.

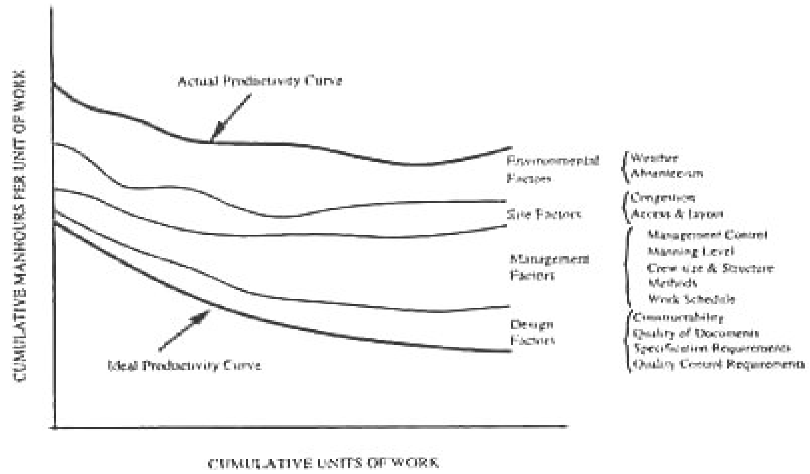

Figure 2- Factor model of construction productivity (Thomas & Yiakounis 1987).

Thus, the theory factor model can be used as a framework for quantifying the effects of various factors on construction productivity, because it provides procedures for collecting data on a daily basis and combining it with the data from different activities to see the effect on the learning-curve. Procedures will allow that the information already obtained together with collection of new information for future research to develop a reliable mathematical model that uses different approaches.

3.3.4 Conceptual construction process model

Sanvido (1988) developed "***a conceptual model of the management functions that are required to improve the productivity and performance of site construction operations (Fig. 3)***". According to Sanvido (1988) ***"the basic features of the model are: (1) definition of the basic tasks of the crafts workers and the input resources required; (2) identification of interrelationships between different functions involved in supporting the field construction process and specification of rules to govern their performance; (3) definition of the scope and boundaries of the on-site construction process; and (4) categorization of external influences on***

the construction process that are beyond the control of the site personnel”. Figure 3 shows several of these concepts.

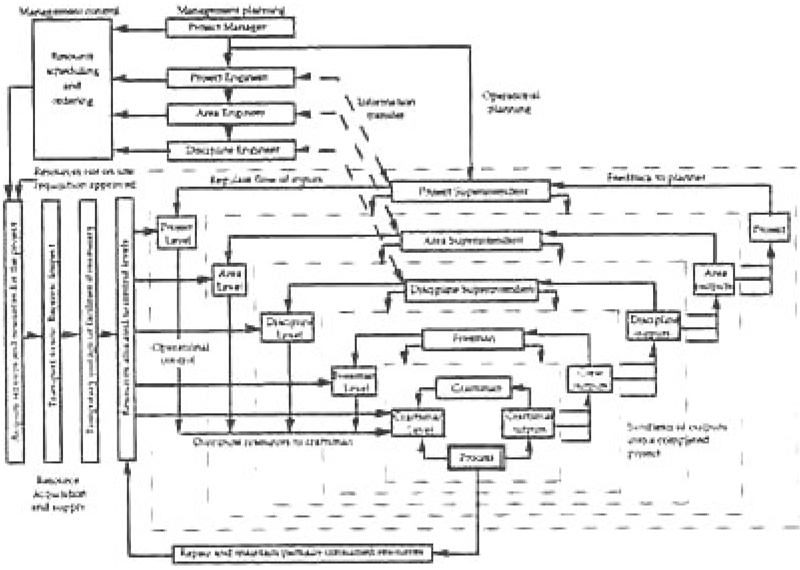

Figure 3- Interplay among authority, responsibility, and communications on every work-face task on a large construction project (Sanvido 1988).

This model signifies a structure of functions to be executed on a project. Sanvido (1988) claims that ***“projects that function closer to the ideal case specified by the model perform better in terms of schedule, cost and quality than those which are further from the ideal situation”***. The author presents a methodology that can be used to improve the productivity of construction projects. It will serve both planning and monitoring roles by permitting comparisons between the ways responsibilities should actually be assigned on a project.

3.3.5 Casual models

According to Alarkon (1993) ***“Borcherding et al. (1986) provide an interesting qualitative model to identify causes of reduced productivity in construction work as shown in Figure 4. Productivity loss on large***

complex construction projects is explained using five major categories of unproductive time: (1) waiting or idle, (2) travelling, (3) working slowly, (4) doing ineffective work, and (5) doing rework. The reason why the crafts workers produce less output per unit of time is relegated to one of these basic non-productive activities. The activities are affected directly or indirectly by several other factors. The diagram illustrates the complexity of the interactions of the numerous factors that affect productivity".

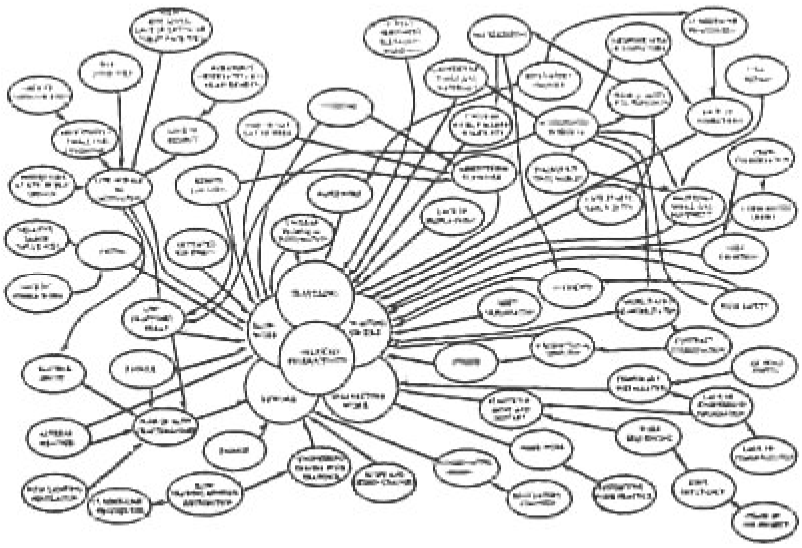

Figure 4- Sources of reduced productivity (Borcherding et al. 1986).

3.4 Traditional combined with new tools to evaluate performance

In this section research is done by illustrating two examples of a traditional and new model to evaluate performance in construction. First example is at the construction site where the measurement technique of work sampling is used to measure waste and detect opportunities for improvement. The second example is at the project level where a new performance modelling technique is used to evaluate the impact of management actions on the performance of a project. These examples are explained by Alarkon (1993).

3.4.1 First example- measuring waste at the construction site

"***This example is based on the work sampling technique that measures time engaged in various activities (Thomas 1981). Work sampling has been used as an indirect measure of productivity but is considered, at best, a surrogate measure of productivity since there is no measure of output. Two assumptions are made to link work sampling results to labour productivity:***

1. It is assumed that reducing delays and waiting time will increase productivity;
2. It is assumed that productive time is related to output and productivity.
These assumptions have been shown insupportable for most construction operations (Thomas et al. 1990) and work sampling has been almost dismissed as a model to measure construction productivity. Nevertheless, Maloney has proposed the use of work sampling as a tool to determine the presence of 'organizationally imposed constraints', within a framework for analysis of performance (Maloney 1990). The experience of several years carried out by a professional team from the Catholic University of Chile (CUCH), with more of 10,000,000 sq. ft. of building construction, has shown that work sampling is an effective tool to promote improvement in construction. The fact that there is no direct correlation between work sampling results and construction productivity does not reduce its potential as a diagnosis and measuring tool for performance improvement. This technique can be used to measure directly different waste categories that are necessary for continuous improvement. The work sampling

model used by the CUCH team focus on specific categories of contributory and non-contributory work as a diagnosis tool to detect sources of reduced performance and to measure improvement. Table 3 shows an example work sampling report used for this purpose. The way this information is structured allows detection of otherwise difficult to detect waste sources. For instance, Table 3 shows that carpenters spend 24% of their time doing contributory work such as transportation of materials; this is an important waste category that can be defined as follows: 'unskilled work performed by skilled labour'. The report structure distinguishes among speciality crews' activities and locations, to help management to compare performance between crews and work areas, facilitating identification of sources of reduced performance.

	Carpentry			**Helpers**			**Steel work**			**Concrete work**		
	PW	**CW**	**Idle**	**PW**	**CW**	**Idle**	**PW**	**CW**	**Idle**	**PW**	**CW**	**Idle**
26/07/93 (M-M)	67	19	15	13	56	31	74	21	5	62	14	24
28/07/93 (W-A)	54	25	21	39	33	28	58	23	19	69	19	13
29/07/93 (T-M)	62	22	16	42	39	19	70	20	10	62	14	24
02/08/93 (M-M)	53	32	15	14	61	24	65	28	8	63	26	11
Average	59	24	17	27	47	26	67	23	10	64	18	18
Old average	52	25	23	24	49	28	68	16	16	54	9	37

PW= productive work; CW= contributory work. Table 3- Work sampling results by speciality

Table 3- Work sampling results by specialty (Alarcon 1993)

Table 4 shows the aggregate result for activities.

	Superstructure			Finishing			Installations		
	PW	**CW**	**Idle**	**PW**	**CW**	**Idle**	**PW**	**CW**	**Idle**
26/07/93 (M-M)	51	27	21	67	19	14	-	-	-
28/07/93 (W-A)	54	24	21	68	20	13	66	14	20
29/07/93 (T-M)	59	22	19	74	12	14	74	15	12
02/08/93 (M-M)	48	32	20	65	23	12	75	6	19
Average	53	26	20	68	18	13	71	12	17
Old Average	49	25	26	54	20	16	56	18	25

PW= productivity work; CW= contributory work. Table 4- Work sampling results by activity.

Table 4- Work sampling results by activity (Alarcon 1993)

Table 5 shows an analysis of contributory work by speciality, the number over the diagonal is the current week average, and the number below is the previous week's result.

Speciality	*Contributory work categories*												*Average Specialty (%)*	
	Tran. -5m		*Tran. +5m*		*Cleaning*		*Instruction*		*Measurement*		*Others*			
	new	*old*	*new*	*old*	*new*	*old*	*new*	*Old*	*new*	*Old*	*new*	*old*		
Carpenter	4	4	2	3	0	0	5	6	10	5	3	6	24	25
Helpers	20	20	12	12	14	5	1	3	0	0	0	0	47	49
Steel work	14	8	2	3	0	0	7	2	0	2	0	1	23	16
Concrete	7	7	3	1	0	0	3	1	3	0	3	0	18	9
Earthworks	5	5	4	4	0	0	3	3	1	1	0	0	13	13
Plaster	5	9	3	0	0	0	2	1	3	4	1	4	15	18
Stucco	5	9	3	0	0	0	2	1	3	4	1	4	15	18
Roofing	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrical	18	7	0	20	0	0	0	0	0	0	0	0	18	27
Sanitary	0	0	15	25	0	0	0	0	8	0	4	0	27	25
Total	8	7	7	10	3	2	3	3	3	3	1	3	25	27

Table 5- Contributory work distribution (Alarcon 1993)

This type of information allows management to take actions and monitor results for evaluation. Some examples of actions taken based on this information are directed to remove ‘organizational constraints’ or ‘minimize waste’, for example: reduce travelling time by providing portable showers or bathrooms, provide materials or tool storage next to the construction site; modify site layout, provide unskilled workers to support skilled workers; provide transportation crews to eliminate travelling and transportation time, and many other practical actions to reduce waste. Observation of the evolution of the different performance elements over a period of time allows measurement of ‘variability’, which has been suggested as a necessary measure for improvement in construction (Koskela 1992). Figure 5 shows the graphical evolution of the classical work categories for work sampling: productive time, contributory work and idle time. In fact, the experience of the CUCH team suggests that a correlation may exist between ‘variability’ in productive work and construction productivity. It has been observed that when variability is reduced in work sampling measures, better productivity is reached at the construction site. This hypothesis is currently under examination.

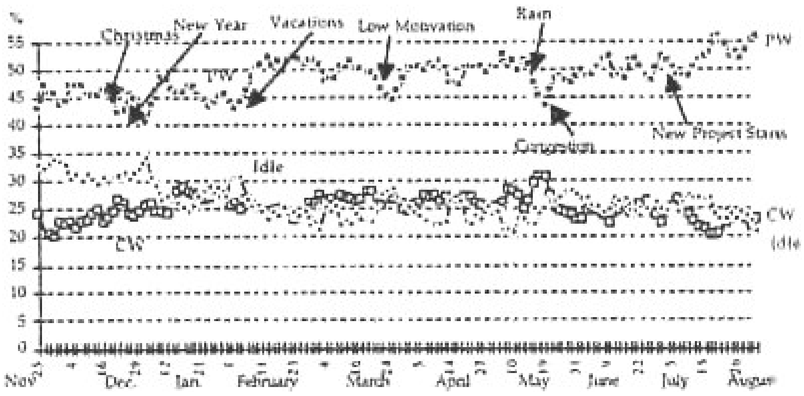

Figure 5- Evolution of work sampling results (Alarcon 1993).

Work sampling used as described plays the role of a sensitive monitor of project performance. Even though it may not reflect productivity

levels, it is very effective in detecting changes in work conditions that are usually associated with inefficiencies and waste sources. In this way it helps management to immediately focus attention on problem areas and provide information for decision making. Foreman Delay Surveys (Tucker 1982) is another traditional tool that has been successfully applied to measure waste in construction. They can complement work sampling results to supply a more precise diagnosis of the causes of delays and job interruptions and provide valuable information to keep track of the improvement effort".

3.4.2 Second example- General performance model (GPM)

"This is a methodology for evaluating performance at a project level. It is a new tool, but it is partially based on concepts proposed in some of the performance models reviewed in this chapter: causal structures, simplified models, qualitative and quantitative relationships for prediction of performance. The GPM was developed by Alarcón & Ashley (1992), working with the Construction Industry Institute's (CII) Project Team Risk/Reward (PTRR) Task Force. It is a performance modelling methodology for application to individual projects which combines experience captured from experts with assessments from the project team. The methodology consists of a conceptual qualitative model structure and a mathematical model structure. The conceptual model structure is a simplified model of the variables and interactions that influence project performance. The mathematical model uses concepts of cross-impact analysis (Honton et al. 1985) and probabilistic inference to capture the uncertainties and interactions among project variables. Project options such as organizational design, incentive plans, and team building alternatives are incorporated into the model knowledge-base. The GPM allows management to test different combinations of project execution options and predict expected cost,

schedule, and other performance impacts. Project performance can be modelled using multiple performance elements defined by the user and a flexible weighting procedure for evaluation" (Alarkon 1993).

3.4.2.1 Model Structure

"The simple model structure, shown in Figure 6, is used to capture, store and link the special expertise of many different parties in the construction industry. The modularization of the knowledge allows for independent elicitation of knowledge from the most qualified experts in specific areas. The model combines the client's preferences, or weights, toward outcomes such as schedule or budget with the special insight of the project team charged with the design, procurement and construction of the facility. Important project management expertise is drawn from CII experts who have judged how the people can drive the processes toward improved performance. Finally, the expertise of the specialists in incentives, or team building, or perhaps partnering, is used to determine how such management actions motivate people.

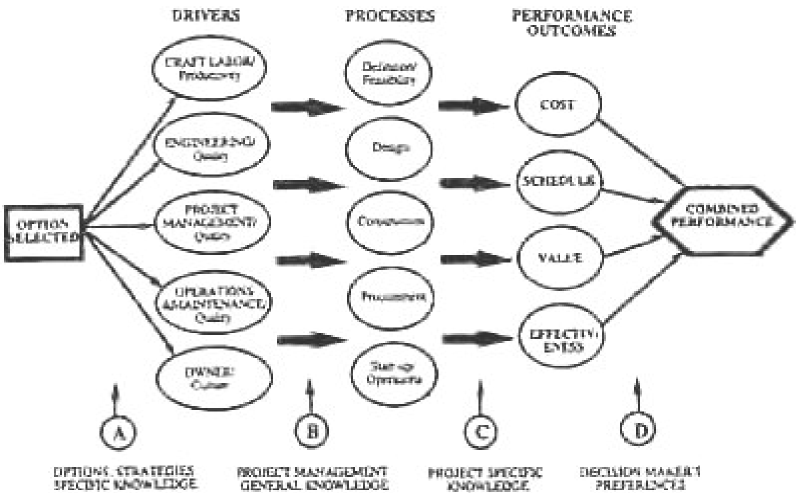

Figure 6- GPM structure and knowledge inputs (Alarcon 1993).

The model can evaluate execution strategies, individually and combined as shown in Figure 7. Starting with the left-hand side of the model, each layer *represents a single option set such as incentives, team building or project organizational structure.*

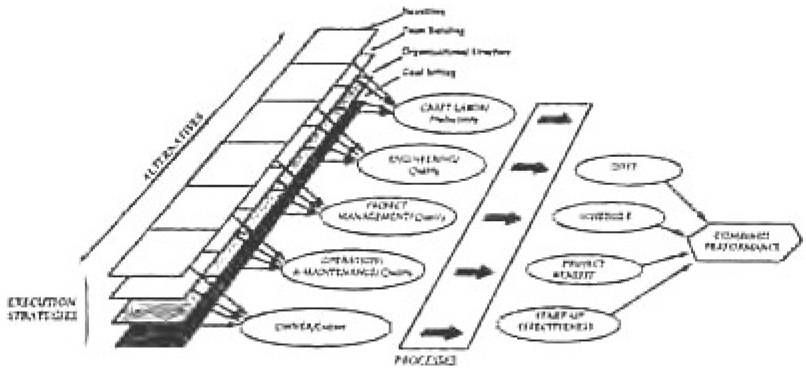

Figure 7- General performance model (Alarcon 1993)

There are many alternatives and combinations of alternatives for each option set. A specific incentive plan can be combined with a specific team building program and choices among the other option areas to form an execution strategy. Following the options there is a set of variables that is directly affected by project options; these variables are called drivers. Each combination of alternatives within an option set is assessed as to its probable impact on drivers. Drivers, in turn, propagate these effects through interactions among themselves and with processes. Drivers include the field labour constructing the project, engineering personnel involved in all design and specification activities, the project management team, key operating and maintenance individuals, and, of course, the client. One way to visualize these people drivers is on the basis of to what degree they achieve their full potential and have the maximum impact on quality or productivity.

The project processes included in the model mirror the typical time phases of a project: (1) definition/feasibility, (2) design, (3) procurement, (4) construction, and (5) start-up/operations. Assessments of how each process will likely impact each outcome are made by the project team on a project specific basis. Direction and magnitude of this effect are both assessed.

The right-hand side of the GPM shows a 'combined performance' box. This measure is obtained by combining several performance outcome measures using weights elicited from top management. The performance outcomes are the true results of the model. The analysis approach developed allows for the *comparison of multiple objectives and the client organization's top management has the flexibility of determining and modifying these objectives by selecting new performance measures. Example performance measures used in this study are project cost, project schedule, the ongoing value or contribution of the facility to the firm and the effectiveness with which the facility is placed into operation. The last two performance measures are examples of new measures necessary for the evaluation in the new production philosophies" (Alarkon 1993).*

3.4.2.2 Analysis capabilities

"The computational scheme utilized within the model allows all possible execution strategies to be compared on a relative basis. Preferred strategies are ranked either on the basis of combined performance or on any single chosen criterion. Figure 8 shows a comparison of the benefits of different organizational structures for a hypothetical project.

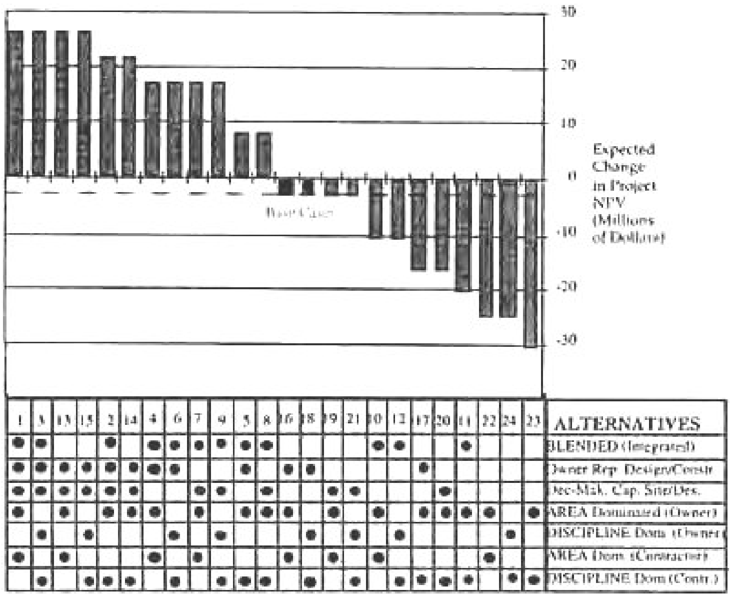

Figure 8- Benefits of organizations (Alarcon 1993)

Analyses can be extended to other options or to a combination of options for the project. Figure 9 shows a comparison of strategies which combine three options: organizational structure, team building and incentive plans. In addition, sensitivity analysis can be performed for selected alternatives to *determine the robustness of any highly ranked strategy, and the drivers or processes with greater impact. The causal structure can be reviewed in detail to gain a better understanding of the performance impact mechanisms.*

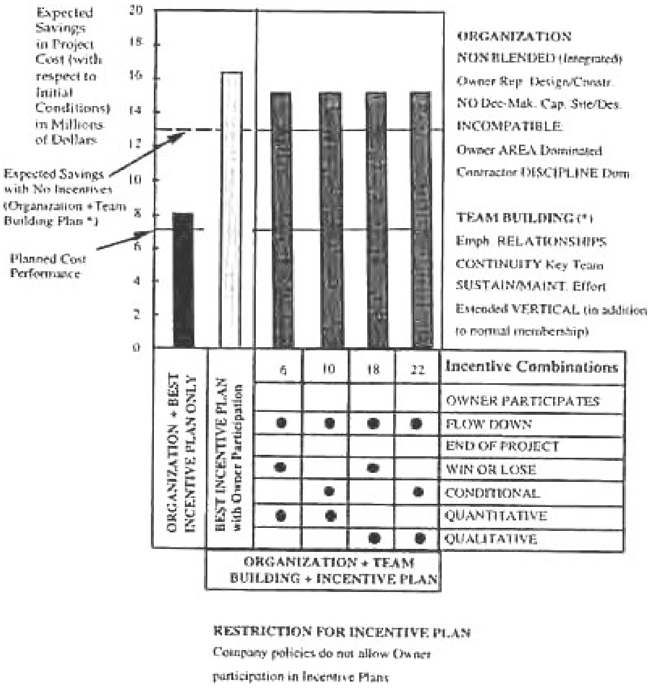

Figure 9- Combined effects: Incentive plan, organization, and team building (Alarcon 1993).

The outputs of this model are predictive, quantified comparisons of project execution strategies in terms of the outcome measures and detailed qualitative and quantitative explanations of the causal interactions. The idea behind this model seems appropriate to evaluate project performance from a general system analysis perspective, to get a better understanding of the global effect of management actions. This modelling methodology can be easily adapted to model project performance for continuous improvement. In fact, Ashley & Teicholz (1993) have recently proposed to use this methodology as a basis to predict the impact of project management actions on industrial facility quality. The effect of project options such as project organization, contractual conditions or data integration on a set of *performance outcomes, which capture a comprehensive evaluation of quality/performance, could be evaluated using this approach" (Alarkon 1993).*

3.5 Conclusion

These models that have been discussed can be applied when introducing the new production philosophy in construction. It is important that the traditional and the new developments meet each other halfway for performance improvement. The examples that have been explained show that traditional concepts and tools can be valuable supports in developing continuous improvement efforts in the construction industry.

3.6 Testing of hypothesis

The hypothesis in chapter one stated:

"Lean construction has specific performance elements which management should focus on (effectiveness, quality, profitability, innovation, etc). The traditional models of project performance are in many ways obstacles to improving construction productivity and offer only a limited set of measures, however it can be used together with the new model to predict and measure performance at the site and project level. Lean construction will thus improve construction performance by using old concepts and implementing new approaches to them".

The hypothesis is mostly correct, in that there are certain performance elements which management should focus on. The hypothesis was also partially correct in the sense that traditional models (measurement models, productivity prediction models, productivity theory factor models, conceptual construction process models and casual models) can be used to measure performance in lean construction but there are however limits to the use of these models in lean construction. That is why traditional models are combined with new tools/models to evaluate the performance in construction companies. They are: the measuring of waste at the construction site technique and the general performance model (GPM) technique.

Chapter four

How will lean construction be implemented in a construction company?

4.1 Introduction

There are two main focuses in Lean Construction- firstly it is on waste and the reduction thereof. Koskela (1992) revealed that there is time and money wasted when materials and information are defective or when it idles. Thus, the efficiency of the conversion process must be improved together with the management of flows between the conversions. Consequently, the other focus will be on the management of flows. This will be done by putting management systems and processes into the spotlight with the production processes.

Lean construction can be implemented on complex, fast track projects. To do so there are a few steps that needs to be followed. The first step is to stabilize the work environment (Figure 10) - by shielding the direct production of each component from upstream variation and uncertainty. Step two is then to reduce the inflow variation- which will be possible because of a shield that is installed which makes it possible to move upstream in front of the shield. And thirdly to improve downstream performance- which will be behind the shield.

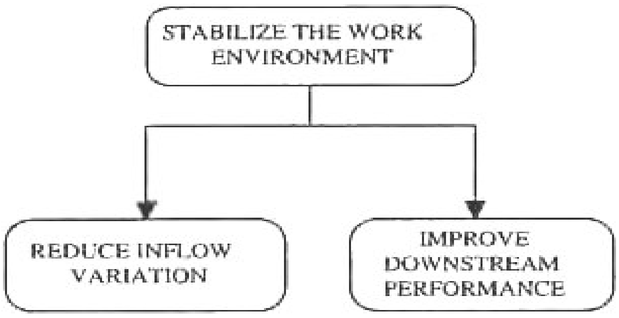

Figure 10- Stabilize the work environment (Ballard & Howell, 1994).

4.2 Stabilize the work flow environment

At every level of the organization decisions regarding- what work to do, in what sequence, over what duration, and what resources and methods to use takes place throughout the life of a project. Sometimes the planner creates assignments that direct physical production. This is where the 'last planner' by Ballard (1994) comes in and takes place last in the chain, because the output of his/her planning process is not a directive for the lower level planning process, and only results in the production phase (Figure 11).

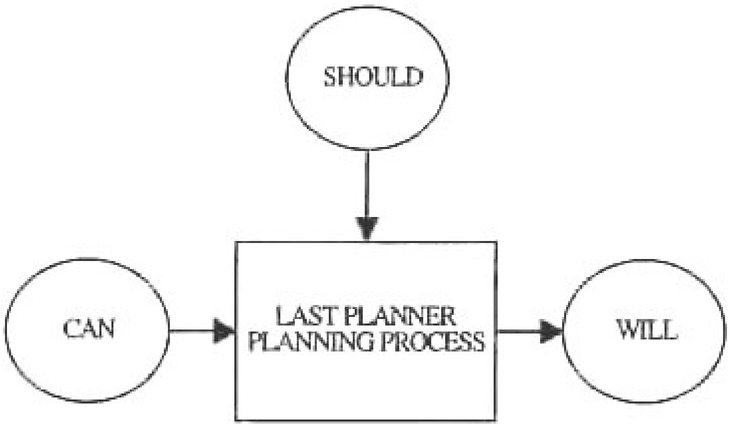

Figure 11- Last planner planning process (Ballard & Howell 1994).

According to Ballard and Howell (1994) "***stabilizing the work environment begins by learning to make and keep commitments. Last planners can be expected to make commitments (will) to doing what should be done, only to the extent that it can be done".*** Thus, choose assignments from a workable backlog meaning from activities that you know can be done. Otherwise, the direct workers will inherit the variation and uncertainty of work flow which will then result in a high percentage of non-productive time and a de-motivated work force not willing to struggle through these difficulties.

There are two primary quality characteristics of the commitment level of planning when selecting or choosing practical assignments. Ballard & Howell (1994) expresses them as "***weekly work plans***" (figure 12).

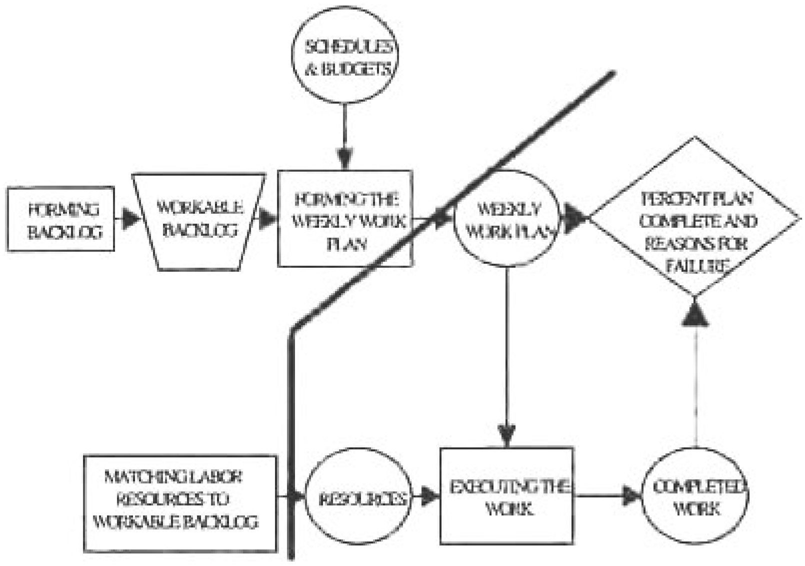

Figure 12- Developing a weekly work plan (Ballard & Howell 1994).

Firstly the right sequence of work is selected- this is the work that moves the project best towards its objectives. Sequencing is schedules developed to coordinate work flow and production activities. They can be made by last planners whom have knowledge of the working conditions and the constructability thereof. Secondly the right amount of work has to be selected. Schedule directs the capacity of the amount of work that the labour and equipment uses.

The last planner commitment level is the first level to be added to the planner system. This shields the direct workforce from upstream variation and uncertainty (Figure 13).

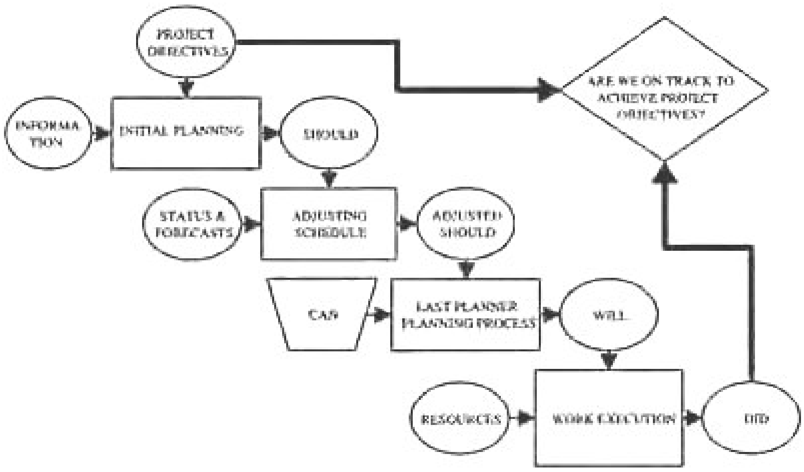

Figure 13- Results-oriented control (Ballard & Howell 1994).

Ballard & Howell (1994) summarizes shielding as "***selecting only assignments that can be successfully completed, assignments for which all materials are on hand and all prerequisite work is complete***".

Benefits of shielding (Ballard and Howell 1994):

- Injects certainty and honesty into the work environment;
- do what you say you are going to do (at least on a weekly basis) and suppliers do the same;
- no blind pressure for production;
- commitment towards learning and improving;
- promotes accountability;
- improves control, especially at the quality of planning and executing at the foremen level;
- confusion and ambiguity are minimized;
- non-productive time is minimized;
- Costs are minimized on time spent waiting on something to work with or moving to alternative work.

4.3 Reduction in flow variation

Considerable variations take place at every step in the construction process. Plans change all the time and materials are mostly late, delayed or not available. When time is of the essence, variation becomes critical and even more apparent as it shows the interdependencies between all the activities. Once the shield to improve downstream operations is in place and the work environment is stabilized through adjusting the planning system, it becomes probable to reduce variation in flows.

Variation is a reality in delivery of any project. A major aspect of Lean Production Theory is to respond positively to this variation. Ballard and Howell (1994) explain that "***buffers between operations are an important tool because they allow activities to proceed independently. Variations in output from upstream operations do not limit the performance of the downstream operation. Buffers can serve at least three functions in relation to shielding work by providing a workable backlog:***

- ***To compensate for differing average rates of supply and use between the two activities;***
- ***To compensate for uncertainty in the actual rates of supply and use;***
- ***To allow differing work sequences by supplier and using activity.***

As valuable as buffers are, they are expensive, hard to size, and hardly an optimal solution. The costs associated with buffers include storage space, double handling, inventory management, loss prevention, buffer fill time, and idle inventory. Buffers are hard to size because the actual supply and use rates are unknown and they vary". Ohno (1987) recognized that buffers were not the best possible solution and warn management about reliance on it. Like he said "you must drain the water from the river to see the rocks, i.e. to find the uninhibited use rates we must make it possible to work without interruptions". Ballard and Howell (1994) used the following example to explain the above:

"***Figure 14 traces the planned and actual delivery of isometric drawings from the engineer to the fabrication shop, the planned and actual fabrication and delivery of pipe to the site, and the planned and actual installation rates. Each stage except the last shows a high degree of variation from the planned rates of provision. This project was built under fierce time constraints. Even so, the installation contractor held to their policy of not starting installation until 85% of the pipe, structural steel and equipment was on site. They believe, and their balance sheet supports, that they can work extremely efficiently and quickly by waiting for the backlog to develop. Oddly, this company only accepts lump-sum contracts so they will not be forced by the owner into inefficient practices. Their policy is to avoid growth so they only bid on enough work to keep their backlog nearly filled with 'high' quality projects. While the strategy works for this contractor, others often proceed with work before a workable backlog exists***".

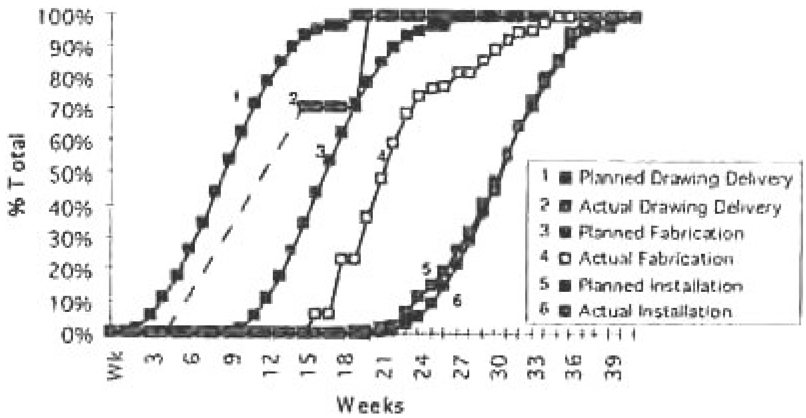

Figure 14- Planned and actual performance of engineering, fabrication and installation (Ballard & Howell 1994).

Plans change. The extent of this change/variation will depend on the different situations of each project.

Figure 15 explains and sums up how to better understand the stages of the expanded planning system (Ballard & Howell 1994).

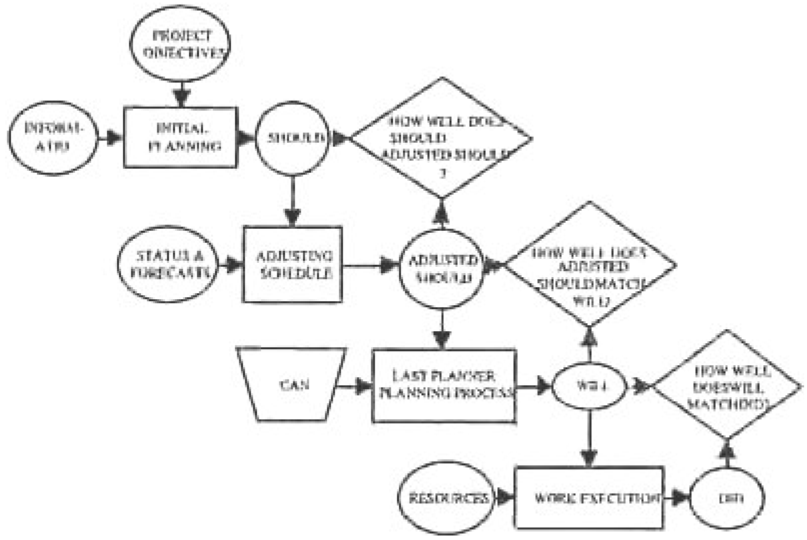

Figure 15- Expanded planning system (Ballard & Howell 1994).

From the top, there are the certain obstacles to consider improving the stability of the initial plan. Directives are in order to ensure that explicit project objectives remain stable. Here and at every other stage control is accomplished and variation minimized by cautious attention to the stability of inputs. This is done by (Ballard & Howell 1994):

- ***Monitoring the basis for the plan***: Identify key assumptions and assign responsibility for monitoring of changes to specific individuals so that any changes can be detected early on. The principle for reducing in flow variation of a project is applied here.
- ***Test the objectives against means for achievement***: Only when the means of the objectives have been carefully examined can they be fixed. The principle of matching ‘should’ with ‘can’ at the outset is applied here.

4.4 Improve downstream performance

To improve downstream performance actually means to look at the operations of the project- improving the performance on construction sites. There is a possibility to minimize the cost and time of operations on a single order of 25-50%, but it isn't easy to realize those increases in the actual cost and time savings. Too many 'man power' on operations may cause failure to balance flows. Lack of discipline in the planning and execution stage will influence the attempts to implement improvements. Thus, stabilization of the work environment is a requirement for operations improvement (figure 16).

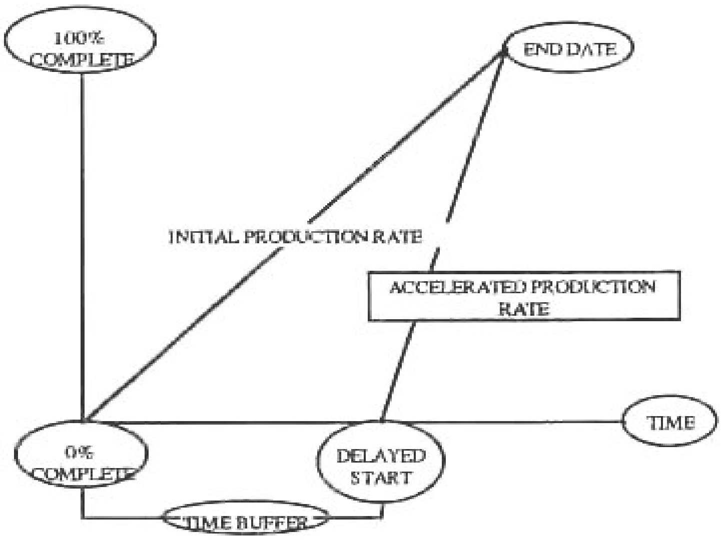

Figure 16- Wait to start, then go faster (Ballard & Howell 1994).

Substantial improvement in operations and the potential in time and cost savings can only be realized when the work environment is stabilized. Then operations are further improved by reducing the inflow variation bringing more benefits and opportunities into the system (figure 17).

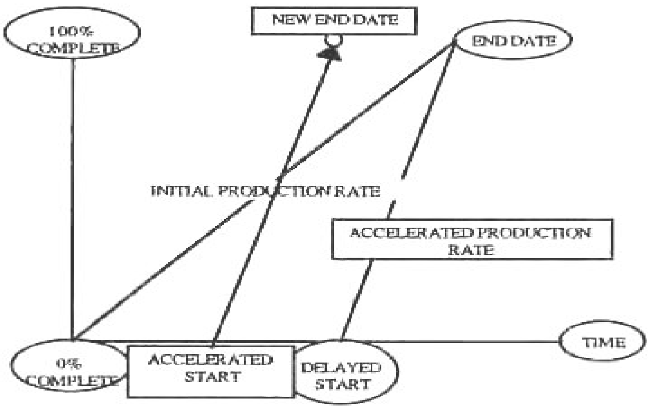

Figure 17- Reduce flow variation, then start sooner (Ballard & Howell 1994).

Phase initiation advances with the simultaneous decrease in delivery variation and size of backlog required to initiate work without risk of interruption. This also improves the optimum sequences that can be selected and better matching of labour resources. It will be possible to change the way work is done. This does not necessarily mean to turn away from planning to execution. Consequently, planning must be extended further downwards in the project phases, because planning addresses both process flow and operations design. According to Ballard & Howell (1994) "***in construction, the effective point of intervention has proven to be the weekly work plan, because that is where work is selected and commitments are made, and the key to stabilization/reduction of uncertainty is improving the ability to keep commitments through better selection of work to be done***". Howell (1993) also highlighted that "***planning goes on beyond the selection of work to be done next week, often by foremen, sub-crew and individual craftsmen as they produce assignments, daily plans and work methods***". The planning system needs to be followed through its final levels, reviewing and improving the plan quality at each of the different levels.

4.4.1 Identifying the variances

The current approach, in the construction industry, is fundamentally flawed in some respects towards the control of costs and schedules. Assumptions are made on budget unit rates applicable to each component, and variances are measured from these assumptions. This leads to false standards in the assessment of performance by managers and foremen. Some of the consequences that arise out these assumptions are (***Ballard and Howell 1994***):

- ***"Near impossibility of identifying a real variance when examining short-term results, and the resultant focus on blaming rather than analyzing; and***
- ***Failure to direct actual production towards project objectives through the provision of reasonable goals; and***
- ***Waste of craft supervision's energies and time spent selecting work and shaping reports so they appear to be working as closely as possible to aggregate averages, and thus avoid drawing fire".***

So, before work starts the decision must be made if the right work has been selected in the right amounts given the work mix and conditions. The right standard of performance for a week is done by plan execution. According to Ballard & Howell (1994) "its measures are Percent Planned Activities Completed (PPAC) and Planned Productivity. ***Budget unit rates are the right standard of labour consumption for a project, and serve as means of calculating and assessing PPAC and planned productivity. When you shift your control focus to adjusted standards, variances can be identified and can be analyzed using reasons why planned work was not done, and you have a chance of improving performance and avoiding repetitive errors. With the prevailing approach to controls, its use of false standards and inability to identify variances, performance improvement is accidental".***

When the field planning system starts working properly- labour will be matched with work to be done, planned productivity will be reasonable, and the right work is done in the right amount. Focus is then turned on the Percent Planned Activities Completed (PPAC) to identify when a performance variance is due to either plan quality or to execute. Variances are then assessed against the planned performance rather than the budget unit rates providing a more efficient analysis of the variances. It also improves accuracy, because it removes the incentives for crafts to move man-hour charges around to reduce apparent variation. Thus, controls should focus on improving PPAC, on-time resource deliveries, and matching labour to resource deliveries. Control can now determine whether the total project and its component parts are on schedule and within budget.

4.5 Conclusion

To conclude it is vital that construction companies learn how to manage in conditions of rapid change and uncertainty because these conditions are the norm for all types of construction projects. Lean construction offers concepts and techniques to meet these challenges. Figure 10, earlier in the chapter, demonstrate how this will be done. First direct production is shielded from variation and uncertainty in the flows of directives and resources. Secondly the flow variation is reduced. And then thirdly performance is improved behind the shield- improving operations within managed flows. Ballard and Howell (1994) state that ***"implementation of lean production concepts and techniques in the construction industry is the way to the future, but following that path requires letting go of traditional thinking".***

4.6 Testing of the hypothesis

The hypothesis in chapter one stated:

"Lean construction can mainly be implemented by reducing the inflow variation, stabilizing work flow, and improving downstream performance. These three implementation strategies need to be incorporated together, because they depend on the results of one another".

This hypothesis was partially correct, in that to implement lean construction there are certain steps that need to be followed (figure 10- stabilize the work flow environment) and that step two and step three can only happen when step one is completed. The first step is to stabilize the work flow (by shielding the direct production of each component from upstream variation and uncertainty), then the second step is to reduce the inflow variation (which will be possible because of a shield that is installed which makes it possible to move upstream in front of the shield), and then the final step is to improve downstream performance (which will be behind the shield).

Chapter five

What tools and methods are used to support lean construction?

5.1 Introduction

There are certain principles that need to be considered when designing tools or choosing the correct tools to use in lean construction. These principles originate from manufacturing and disputes have been made that they are not applicable to the construction industry, but in fact some of them are applicable to the construction industry.

The requirements of tools used in lean construction are divided into two groups: (1) Tools that support reengineering business processes, and (2) Tools that support planning and controlling business processes. The first group consists of methods like activity and cost analyses, and accuracy and delivery time analyses. The second group consists of a tool called TOIMI.

5.2 Principles of lean construction that affect the design of tools.

In the design of tools for lean construction there are certain principles from lean manufacturing that must be considered (Tanskanen, Wegelius and Nyman 1993):

- ***"Focus on material and information flows. The effectiveness of the whole business process that start at design and ends when the final product is handed over to the customer is more***

important than the efficiency of the separate units in the process";

- ***"Eliminate waste. Those operations in the process that do not add any value to the end product must be identified. After that the processes must be redesigned to eliminate the waste";***
- ***"Minimize variances. Standard and simple procedures should be used as much as possible in order to make forecast ability of performance as good as possible. This way we also increase the repetitiveness of processes so that effective development can take place";***
- ***"Consider time a key element of all business processes";***
- ***"Focus on continuous development of the processes instead of sudden and revolutionary changes".***

Arguments have been made that these principles are not applicable to the construction industry, because lean manufacturing is a system for repetitive manufacturing and in the construction industry the products and site organization is unique. Thus, the principles and methods of lean manufacturing cannot be applied. However, in construction we find that the processes are also repetitive. For example, the process of material deliveries for standard materials (made to order) and for customized material (designed to order) follows the same steps in all construction projects. The other argument is about the 'culture' of the construction industry that includes standard procedures (individual professionality is emphasized) and accepts long throughput times and poor accuracy. However, the evolution of manufacturing systems of the automotive industry in Japan shows that cultural aspects do not prevent the development of manufacturing systems. The automotive industry in Japan suffered the same kind of problems that most construction companies throughout the world suffer from today: long throughput times, bad accuracy, poor quality, etc. And today in Japan the automotive industry has a changed 'culture' that supports lean manufacturing which evolved through long lasting and hard work. No evidence can be found that similar kind of development cannot take place in the construction industry as well.

5.3 Requirements for tools used in Lean Construction

The tools used to support lean construction are categorized into two groups by Tanskanen, Wegelius and Nyman (1993):

1. ***Tools that support reengineering business processes;***
2. ***Tools that support planning and controlling business processes.***

5.3.1 Tools that support reengineering business processes

Reengineering is evidently a management job, but this does not mean that managers should do it and then at the same time tell workers how they should operate and do their job. The support managers provide is obviously very valuable but it is very important that workers who are in charge of the daily operations should be involved in the development process. According to the experience of Tanskanen, Wegelius and Nyman (1993) "***the following are the key issues in the development process:***

- ***The business processes to be developed are identified and the current performance level is measured;***
- ***Current performance is benchmarked with 'best practices' in order to identify improvement potential;***
- ***Ideal models are provided to guide the reengineering process. Although the 'ideal model' might be not applicable in all conditions, it shows the right direction".***

Tanskanen, Wegelius and Nyman (1993) did surveys which indicated that the Finnish construction industry is still far from reaching current practice: unknown business processes, do not measure current performance levels, unclear development potentials, and unknown 'ideal models'. Instead, the 'ordinary model' is used by planners and foremen when designing the processes or planners. Foremen do not design them at all, the work just happens.

5.3.2 Tools that support planning and controlling business processes

Modern information technology effectively supports the planning and controlling business processes of the construction industry. There are however unclear things to take into consideration, which is not reasonable, when a computerized decision is made. This is why the tools of lean construction combine the strengths of both human and computer:

- **Computers:** have strong characteristics in storing, sorting, calculating and transmitting large quantities of data.
- **Humans:** have strong characteristics in combining information, reasoning and making decisions.

Thus, for human interpretation it is exceptionally vital that information is presented and processed in such a way that the planner is recognizable with. This means that in practice the user interface of the system must not only be graphical but also be able to use it interactively.

The process of how we design the computer system is very important. But before the tools can be specified, there needs to be a thorough understanding of the goals of the planning task. According to Tanskanen, Wegelius and Nyman (1993) in lean construction this means that "***we don't just automate routines; the tool must also support continuous***

improvement of performance, and provide feedback on development of performance. The system must also be flexible enough to fit different kinds of environments. Therefore prototyping approach is the best for designing tools for lean construction". The requirements for lean construction planning and controlling tools are summarized by Tanskanen, Wegelius and Nyman (1993) as:

- ***"Graphical presentation of information;***
- ***Interactive way to process information;***
- ***Understand and specify the goals of planning and controlling;***
- ***Support continuous improvement of performance;***
- ***Provide feedback on the actual trend of the performance of planned business process".***

TOIMI is an example of a tool consisting of the above requirements and will be discussed later in this chapter.

5.4 Methods for reengineering business processes

There are two methods that can be used for reengineering business processes or for analyzing non-value-adding activities of business processes. The two methods are (1) activity and cost analyses and (2) accuracy and delivery time analyses.

5.4.1 Activity and cost analyses

This method is based on the theory of activity-based costing. The principle of this theory (activity-based costing) is that processes of the company are divided into activities and each activity uses different resources. The purpose of this method (activity and cost analyses) is to calculate the costs of unnecessary work and then to eliminate the problems that cause these costs. The advantages of this method (activity and cost analyses) are that firstly it helps people to focus on the most expensive activities and secondly it shows concretely the potential for cost savings.

To calculate the waste in the business process of construction projects, all the companies (contractor, subcontractors, design offices, and material suppliers) involved in the process need to co-operate. In co-operation the first step is to improve business processes by using this method (activity and cost analyses) to calculate what the processes are today and how to improve these processes. Tanskanen, Wegelius and Nyman (1993) choose the material group and the sites to be analyzed to explain the activity and cost analyses method. There are three steps involved in this method as explained by Tanskanen, Wegelius and Nyman (1993):

1. ***"The first step of the analyses is to identify all activities in the business processes. For <u>standard materials</u>, the business process starts with placing an order and ends when materials are assembled. For <u>customized materials</u>, the business process starts when architectural design starts. The focus is on non-value-adding activities (moving, storing, inspecting, sorting etc.), which are modelled in details. The value-adding activities (production, design etc.) are described on a rough level. This stage in the analyzing process is called <u>activity analysis</u>.***

2. ***After identifying the activities, the second step is to <u>measure the costs</u> of non-value-adding activities. For this purpose we use pre-calculated standard costs, for example, dollars per square meter of in-house warehouse per day. By using standard costs we can better identify the effectiveness of the total process instead of efficiency of separate activities. Finally, the costs of capital tied up to the process are added. After summing up the costs of non-***

value-adding activities of the selected business process, we calculate the non-value-adding costs/total costs -ratio. Different kind of graphical presentations are also used for illustrating the costs of non-value-adding activities.

3. ***The third step is to <u>benchmark current performance</u> of different construction sites and to try to find out 'best practices'. An ideal model for the whole business process is defined by combining the best practices from analyzed cases. Improvement potential can be identified by comparing the current practice to the ideal model. The redesign process aims at improving current performance towards identified ideal models by continuous development".***

5.4.2 Accuracy and delivery time analyses

This method (accuracy and delivery time analyses) has been developed to calculate the time lags in material and information flows. This method calculates the accuracy of all the companies (design offices, contractors, and material suppliers) involved in the process with these analyses. The purpose of this method (accuracy and delivery time analyses) is to simplify the configuration of the delivery time and to discover opportunities to shorten this time. Generally the activity and cost analyses method and the accuracy and delivery time analyses method are applied at the same time, because the results of each method supports the other. Thus the material group and the sites that will be analyzed are usually similar in both methods. Accuracy and delivery time analyses are very simple to implement. This implementation is clearly explained by Tanskanen, Wegelius and Nyman (1993):

1. ***"First the important <u>time points</u> in both the material and the information flows are defined and included to the analyses. For***

non-standard materials it is necessary to analyze also accuracy and lead time of the design process. It is essential to analyze both the planned and the actual points of time. This way accuracy of the material delivery process can be clarified. The ordering day, the planned and the actual day of manufacturing and the planned and the actual delivery day are some examples of these time points.

2. ***The second step is to collect the analyses data from different sources. It is necessary to use documented data from the planned and the actual time points. If documented plans are not available, the processes are probably not planned and controlled well enough. Documented data can be found for example in delivery orders, production plans, construction site diaries and installation plans.***

3. ***The most informative way to present the results of accuracy and delivery time analyses is to use graphs. This way time lags and delays in the delivery processes can be easily clarified. For example the analyses show if a material delivery has arrived to the site many weeks before installation. Benchmarking is a useful method also in analyzing delivery time and accuracy. 'Best practices' show improvement potential and developed ideal models guide the redesign process in the right direction".***

5.5 Method for planning and controlling material supplies at construction sites

TOIMI is a computerized (PC-based software) tool developed for planning and managing material deliveries of construction sites.

5.5.1 Objectives and principles of TOIMI

The objective of TOIMI is to:

- Make the division of material purchases into smaller deliveries easier based on the actual need therefore;
- Help the management of incoming material flow;
- Assist in the specification of the contents, time points, and unloading places of the deliveries.

Frequently in a construction project more than 50% of the costs are from different materials purchased. Purchase prices need to be observed, on a regular basis, in construction companies. The costs of activities that occur after the purchasing agreement is signed are usually overlooked. A number of operations need to be completed before the material is ready to be installed. Studies have shown that construction companies can achieve major cost reductions by systematically planning and controlling the incoming material flow.

However, when the time points and contents of the deliveries are planned accurately it becomes very wearisome to divide the material purchases into smaller deliveries. Consequently, the difficulties involved in managing the purchases will increase directly as the number of deliveries increase, and as the inventories get smaller the risk concerning the punctuality and correctness of the deliveries becomes greater. A worst case scenario will be where the mistakes in delivery planning delays the whole project at which point the total effect of the planning process quickly turn unprofitable.

Thus, TOIMI has not only been developed to ease the division of the purchases into appropriate deliveries according to the need of materials but also to support the management of incoming deliveries. The person who is normally responsible for the deliveries and scheduling on the construction site will usually be the primary user of TOIMI. TOIMI is easy and illustrative to use because the software is based on simple colour codes shown on calendar views, concepts familiar to the user, and visual scheduling. The idea of TOIMI is to provide information to the user, easily and clearly, to timely plan and control purchases.

5.5.2 Main functions of TOIMI

According to Tanskanen, Wegelius and Nyman (1993) ***"the following events are important when managing a single delivery:***

- ***Rough planning of the purchase, i.e. preliminary division of the purchase into deliveries and defining the time points (delivery weeks) and contents of the deliveries;***
- ***Scheduling of the delivery as the agreed/fixed time point draws closer, i.e., 1) Determining the date of the delivery, the unloading places on the site, and the final content of the delivery, and 2) Sending the supplier the delivery order, including the mentioned details:***
    - ***– Confirmation of the ordered delivery by the supplier;***
    - ***– Acceptance inspection on the site;***
    - ***– Possible reclamation".***

TOIMI has been developed and designed to support the abovementioned functions. The user of TOIMI uses illustrative colour codes to manage the deliveries arriving to the construction site- this helps the user or users to directly see the state of the deliveries. The deliveries can then further be examined in calendar view in either:

- **Relating to a particular purchase:** where all the deliveries of the purchase and their state in a weekly calendar are shown.
- **Within a chosen time period:** where all the deliveries coming to the site within a month and the state of these deliveries are shown.

TOIMI is a Microsoft Windows-based application and to run this program it requires at least 4 MB of memory and a 368-processor. The colour codes are used to display deliveries at an agreed delivery date (they are also analogous to those used in a traffic light):

- **Red:** means that the delivery has not been planned (it gives the alarm).
- **Yellow:** means that the delivery has been planned, the delivery order has been sent, but the supplier has not yet confirmed or approved the delivery (warns).
- **Green:** means that the supplier has confirmed or approved the delivery (signals that everything is fine).

Once the user sends the delivery order or when the confirmation of the supplier arrives, the system automatically changes the state and the colour code of the delivery. Thus, when choosing for example a summary of all the deliveries coming to site in the upcoming month the user would be able to immediately observe the possible problems and next tasks to perform by simply examining the colours on his display.

In addition, TOIMI can also make complete delivery orders and delivery reports according to the instructions of the user. These orders and reports can for example be used in weekly site meetings or month-end meetings. The information filled in the delivery order can be entered into TOIMI via inspection. By using TOIMI regularly on different sites of the company, the accumulated information can for example be used to follow up on the performance of different suppliers.

5.5.3 Future improvement of TOIMI

According to Tanskanen, Wegelius and Nyman (1993) ***"the development of TOIMI began in the summer 1992, and the pilot version of the software was tested on a construction site at the end of the same year. The software has been further developed according to the feedback given by the users. Currently TOIMI is in pilot operation on six different construction sites. The experience gained at the pilot sites indicate that the tool is useful and deserves further development. Further development will be focused on following areas:***

- ***Building connections between TOIMI and project management software;***
- ***Building connections between TOIMI and cost accounting software;***
- ***Modifications of TOIMI for small contractor companies;***
- ***Fastening TOIMI by rewriting major parts of the code.***

5.6 Conclusion

In conclusion, there are principles that are used in manufacturing tools that also applies to tools that are used in lean construction. They are: Focus on material and information flows, focus on continuous development of the processes instead of sudden and revolutionary changes, minimize variances, consider time a key element of all business processes, and eliminate waste.

Tools to be used in lean construction are categorized into two groups: first group is tools that support reengineering business processes which consists of methods like activity and cost analyses, and accuracy and delivery time analyses; and the second group is tools that support planning and controlling business processes which consists of a tool called TOIMI. These tools are used in the construction industry and on construction sites to support the new lean construction concept.

5.7 Testing of hypothesis

The hypothesis in chapter one states:

"When developing tools for lean construction, there are certain principles that need to be considered. There are two categories for the tools that support lean construction: (1) tools that support reengineering business processes, and (2) tools that support planning and controlling business processes. The first tool (reengineering business processes) that can be used in lean construction contains two methods: (1) activity and cost analyses, and (2) accuracy and delivery time analyses. The second tool (planning and controlling business processes) that can be used in lean construction is a PC-based software, called TOIMI".

The hypothesis is correct and these tools that are mentioned in the above statement can be used as tools to support lean construction.

Chapter six

Concluding the main problem

6.1 Background

The construction industry in South Africa is not perfect and there are all kinds of chronic problems. These problems also exist in other countries around the world. In some of these countries (like Japan, America and some European countries) they developed a new production philosophy, called lean construction, which was developed to solve these problems.

The objective of this treatise is to investigate this process called Lean construction to see what it is; how it is implemented; how its performance can be measured; and what tools are used to execute lean construction in a construction company. The sole point of this investigation will be to show that this new form of production management should become part of a construction company's objective, aim and goal in South Africa and will not only help these companies to solve chronic problems in a construction company itself but also on the different sites of the construction company. This will not only apply for Construction companies in South Africa but also for construction companies around the world.

6.2 Summary

In order to attempt to answer the main problem, four sub-problems had to be considered so as to gain a deeper understanding of the underlying factors that relate to the problem.

The ***first sub-problem*** considered, dealt with: *"What is lean construction and is it a new concept"*?

Research found, by consulting of different textbooks and articles that lean construction has been around for a couple of years. It is still a new concept in certain countries but in theory it has been around for a few years. Countries like Japan, America and certain European countries use the new production theory. It has not been fully practiced or implemented in certain countries, including South Africa, and thus making it "new" for them.

Lean construction is a new production philosophy which stresses the importance of basic theories and principles in the production system and aims to meet client requirements while using less of everything. Lean construction is suited to any kind of construction project, but mainly for uncertain, complex and fast track projects. As can be seen in table 1 in chapter 2, waste does exist in construction companies and lean construction will reduce this waste if the appropriate measures are taken and the new philosophy implemented.

Lean construction supports the development of teamwork along supply chains and also shifting the burdens along the supply chain. This means that lean construction not only focuses on building trust, but also on building reliability.

The ***second sub-problem*** considered, dealt with: *"How will the performance of lean construction be measured in a construction company"?*

This sub-problem was answered by looking at different models of the new production philosophy in construction. Research showed that it is important that the traditional and the new developments meet each other halfway for performance improvement. The examples that have been explained in chapter three show that traditional concepts and tools can be valuable supports in developing continuous improvement efforts in the construction industry.

The ***third sub-problem*** considered, dealt with: *"How will lean construction be implemented in a construction company"?*

Research showed that construction companies need to learn how to manage in conditions of rapid change and uncertainty, because these conditions are the norm for all types of construction projects. Lean construction offers concepts and techniques to meet these challenges. First direct production is shielded from variation and uncertainty in the flows of directives and resources. Secondly the flow variation is reduced. And then thirdly performance is improved behind the shield- improving operations within managed flows.

The ***forth and final sub-problem*** considered, dealt with: *"What tools and methods are used to support lean construction"?*

Research found that the principles that are used in manufacturing tools also apply to tools that are used in lean construction. They are: Focus on material and information flows, focus on continuous development of the processes instead of sudden and revolutionary changes, minimize variances, consider time a key element of all business processes, and eliminate waste.

The tools used in lean construction are categorized into two groups: first group is tools that support reengineering business processes which consists of methods like activity and cost analyses, and accuracy and delivery time analyses; and the second group is tools that support planning and controlling business processes which consists of a tool called TOIMI. These tools are used in the construction industry and on construction sites to support the new lean construction concept.

6.3 Conclusion

Finally the time has come to reach a conclusion on the main problem of this treatise. Throughout the proceeding supporting chapters a lot of focus has been placed to see if lean construction should become part of a construction company's objective, aim, and goal.

It is therefore, based on the findings that firstly, lean construction is a new and unique production philosophy that will enable a construction company in South Africa and in other countries to become more efficient, reliable and trustworthy once implemented. Chronic problems that exist in a construction company will be eliminated and resolved.

Secondly, the performance of lean construction can be measured and will improve and make an impact on the way production and management is done in a construction company. Methods that exist needs to be modified with the new production methods and will provide continuous improvement in a construction company.

Thirdly, research shows that lean construction will help a company to learn how to manage in conditions of rapid change and uncertainty, because these conditions are the norm for all types of construction projects.

Lastly, research showed that there are different types of tools that can be used in the construction industry to support lean construction.

Thus, in final conclusion, it is found that lean construction can and should be part of a construction company's objective if the company wishes to survive and make its mark in the construction industry. Time is of the essence and you can either sit back and stick to what works or try to go with the flow and improve the company in a way no other can compete.

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