A PROCESS TO ASSIST TECHNOLOGY INVESTMENT DECISIONS IN CONSTRUCTION - A CASE STUDY ON LABOUR PRODUCTIVITY

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Declaration

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Abstract

Worldwide the civil construction industry is one of the biggest and most influential industries but has proven to be lacking in the development of technology-aided construction. In contrast, the automotive manufacturing industry is very reliant on the use of highly advanced technology. Literature showed that specific focus is being put on increased technology investments and development of infrastructure in South Africa in order to solve various problems in the country.

In light of these realisations, the objective of this research study was to establish a process that can be used to assist technological investments that solve areas of concern in the construction industry.

The research was conducted by following a procedure of identifying problematic areas in construction, scrutinising the biggest problem to identify its key elements and finally selecting a decision support model to select technological solutions. The research sequence therefore established the steps of a process that can assist technological investment decisions that solve areas of concern in the construction industry.

The first step of this process necessitated the identification of the most influential area of concern in South African construction. A series of interviews and surveys with experienced senior managers in different divisions of the South African civil construction industry showed that the low productivity of labourers is the most influential area of concern in terms of impact on construction projects. Consequently, labour productivity was scrutinised as part of the second step of the process. It was found that there are different methods to measure productivity and that factors influencing labour productivity can be grouped into managerial practices, labour effectiveness and material timeliness. The scrutiny, together with the productivity improvement system and lessons learned from other industries, gave input to the third step of the process, viz. to identify technological solution alternatives for the area of concern. Wireless technology and visual analysis were identified as two groups of technology that could improve labour productivity. The final step of the process evaluated the effects the different solution alternatives could have on a company and a tailored set of criteria together with a fuzzy multi-criteria decision model was proposed for use in this step.

The research study identified that there are generic areas of concern in construction and that technology can be used to improve problem solving processes in companies. Furthermore, a generic and flexible four step process was formulated that can incorporate multiple criteria, stakeholders' opinions, business strategy and the necessary benefits the problem requires in one evaluation model. This process was found to be able to assist technological investment decisions in the construction industry specifically to eliminate or improve on existing areas of concern.

Opsomming

Die siviele konstruksiebedryf is een van die grootste en mees invloedryke industrieë wêreldwyd, maar is bewys om agter te wees in terme van ontwikkeling in tegnologie-gesteunde konstruksie. In teenstelling hiermee is die motor-industrie afhanklik van die gebruik van hoogs-gevorderde tegnologieë. Literatuur het getoon dat daar spesifiek gefokus word op die investering in tegnologie- en infrastruktuurontwikkeling in Suid Afrika sodat bestaande probleme in die land opgelos kan word.

In die lig van hierdie bevindinge, is die doel van hierdie studie om 'n proses te vestig wat kan help om besluite rakende tegnologiebeleggings te vergemaklik sodat probleem areas in die konstruksie industrie met dié beleggings opgelos kan word.

Die eerste stap van die navorsingsprosedure was om probleem areas in die konstruksie industrie te identifiseer en daarna is die probleem met die grootste impak op konstruksie projekte in diepte ontleed om die eienskappe daarvan te bepaal. Laastens is 'n besluitnemings model gekies sodat tegnologiese beleggings geëvalueer en gekies kan word. Die navorsingsprosedure het daarom die struktuur gegee om 'n proses te vestig wat gebruik kan word om besluite oor tegnologiese beleggings te vergemaklik om sodoende probleme in die konstruksie industrie op te los.

Die eerste stap in hierdie proses het vereis dat die probleem met die grootste impak op konstruksie projekte in die Suid-Afrikaanse konstruksie industrie geïdentifiseer moes word. Na afloop van 'n reeks onderhoude en opnames met ervare senior bestuurders in verskeie afdelings van siviele konstruksie, is gevind dat lae arbeidsproduktiwiteit die mees invloedryke probleem area is. Lae produktiwiteit van arbeid is om hierdie rede in diepte ontleed as deel van die tweede stap in die proses. Daar is gevind dat daar verskillende maniere is waarop produktiwiteit gemeet kan word en dat faktore wat produktiwiteit beïnvloed gekategoriseer kan word in bestuur praktyke, arbeid effektiwiteit en stiptelikheid van materiaal. Die ontleding, tesame met die produktiwiteitsverbeteringstelsel en lesse wat geleer is in ander bedrywe, het gelei tot die derde stap van die proses, naamlik die identifisering van tegnologiese oplossings-alternatiewe. Draadloostegnologie ("wireless technology") en visuele analise is geïdentifiseer as twee groepe van tegnologie wat die produktiwiteit van arbeid kan aanspreek. Die finale stap van die proses het gebruik gemaak van 'n stel kriteria en 'n '*fuzzy multi-criteria'* besluitnemingsmodel om die verskillende tegnologie alternatiewe te evalueer.

Hierdie navorsingstudie het daarin geslaag om te identifiseer dat daar generiese probleem areas in die konstruksiebedryf is en dat tegnologie gebruik kan word om probleme op te los en om dienooreenkomstig siklusse in maatskappye te verbeter. Verder is 'n generiese en buigsame vier-stap proses geformuleer wat verskeie kriteria, opinies van belanghebbendes, korporatiewe strategieë en die

nodige voordele om die probleem op te los, alles in een evalueringsmodel inkorporeer. Hierdie proses is bewys om te kan help om tegnologiese beleggings in die konstruksiebedryf te vergemaklik om sodoende reeds-bestaande probleme op te los.

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Glossary

In-text Abbreviations	
AHP	Analytical Hierarchy Process
BCEA	Basic Conditions of Employment Act
BIM	Building Information Modelling
CEO	Chief Executive Officer
CIDB	Construction Industry Development Board
CMP	Construction Management Programme
COP	Conference Of Parties
COW	Clerk Of Works
CPI	Continual Process Improvement
CPM	Critical Path Method
CSCE	Canadian Society for Civil Engineers
CV	Crisp Value
DM	Decision Maker
ECSA	Engineering Council of South Africa
EPWP	Expanded Public Works Programme
EUCAR	European Council for Automotive Research and development
ELECTRE	ELimination Et Choix Traduisant la Realite
FET	Further Education and Training
FIDIC	French Acronym for International Federation of Consulting Engineers
GCC	General Conditions of Contract
GGDP	Global Gross Domestic Product
GPS	Global Positioning System
ICT	Information and Communication Technology
ICV	Ideal Cycle Variability
IS	Information Systems
IT	Information Technology
JBCC	Joint Building Contracts Committee
MCDAP	Multi Criteria Discrete Alternative Problem
MCDM	Multi Criteria Decision Model
MCOP	Multi Criteria Optimisational Problem
MEW	Multiplicate Exponential Weighting
MPDM	Method Productivity Delay Model
MPP	Material Procurement Planning
NDP	National Development Plan
NEC	New Engineering Contract
NPC	National Planning Commission
OCV	Overall Cycle Variability
OMP	Overall Method Productivity
R&D	Research and Development
RFID	Radio Frequency IDentification

SAFCEC	South African Federation of Civil Engineering Contractors
SAICE	South African Institution for Civil Engineering
SAW	Simple Additive Weight
SETA	Skills Education Training Authorities
SOE's	State Owned Enterprises
TFN	Triangular Fuzzy Number
TFP	Total Factor Productivity
TOPSIS	Technique Of Preference by Similarity to the Ideal Solution
TPQ	Team Performance Questionnaire
UK	United Kingdom
UWB	Ultra Wide Band
VA's	Voluntary Associations
WPM	Weighted Product Model
WSM	Weighted Sum Model
Symbols for in-text calculations	
O	Area of concern
R	Rating given to an area of concern
M	Manager/Interviewee
R_A	Average rating for an area of concern
D	Delegate
T_d	Time influence according to delegate *d*
C_d	Cost influence according to delegate *d*
Q_d	Quality influence according to delegate *d*
R_d	Risk influence according to delegate *d*
I_T	Average impact the area of concern has on Time
I_c	Average impact the area of concern has on Cost
I_Q	Average impact the area of concern has on Quality
I_R	Average impact the area of concern has on Risk
I_{AVE}	Total average impact value of the area of concern on a construction project
C	Criterion
A	Alternative
$\breve{N}$	Triangular Fuzzy Number
L	Lower limit value of triangular fuzzy number
M	Most likely value of triangular fuzzy number
U	Upper limit value of triangular fuzzy number
$\mu(x)$	Membership function
K	The amount of individuals in the weighting team
K	Represents one individual in the weighting team
$[FRM^k]$	Fuzzy reciprocal matrix of member k in the weighting team
C_{ij}^k	Comparison of criteria C_i with criteria C_j by the k^{th} member
$\bar{C}_{ij}$	Aggregated value of the comparison of criteria C_i with criteria C_j
$[F\bar{R}M]$	Aggregated fuzzy reciprocal matrix
r_i	Geometric row mean of criteria C_i within the respective $[F\bar{R}M]$

w_i	Local weight of criteria C_i in the respective $[F\bar{R}M]$
$\bar{w}_i$	Global weight of criteria C_i
S	The number of individuals in the scoring team
S	Represents one individual in the scoring team
x_{ij}^s	Performance score of alternative A_i with regards to criteria C_j by member *s*
$[X^s]_{ixj}$	Score matrix of member *s* with *i* rows and *j* columns
A	Amount of alternatives to be considered
n	Amount of criteria compared to at a time
$\bar{x}_{ij}$	Aggregated performance score of alternative A_i with regards to criteria C_j
Z_i	Final TFN score of alternative A_i
CV_i	Crisp value of alternative A_i

CHAPTER 1

General Introduction

This chapter provides a general introduction to this research study, outlining key elements of the research process employed, thus facilitating easy navigation throughout the remainder of the document.

The inspiration for the research will be discussed and will serve as the point of departure for this thesis. The problem statement and research objectives are provided which outline specific discussions that guided the structure of the current research study. The methodology employed to conduct the current research is also discussed - so that it is clear why specific fields were investigated. Finally an outline of the thesis document is given, providing a logical flow of the document.

1.1 Inspiration for the research thesis

This research document will, throughout the different chapters, work through a process that could be used to assist decision-making with regards to technology investments in construction companies. This specific field was inspired by the realisation formulated by studying two areas of literature.

The first area of literature that provided inspiration for research on this topic was the difference of developments in large, yet comparable industries. The literature investigated within this area was specifically focused on the developments and differences of the construction industry with regards to the automotive manufacturing industry. The second area of literature, focused on South Africa and the developments of the country in a global context. The investigation of the developments in South African was narrowed down to the technological development of the country because of the realisations that surfaced while comparing the construction and automotive industries.

The next two sections will discuss these two areas of literature, which will provide supporting information to support the relevance of the topic of this research thesis.

1.1.1 Construction industry versus the automotive manufacturing industry

The construction and manufacturing industries are two of the biggest and most influential industries globally (World Bank Group, 2011). Besides the similarity in the fact that both of these industries have major global influence, these two industries have significant differences. This section will focus on how these two industries compare to each other.

1.1.1.1 Construction industry and the slow adoption of technology

According to the business dictionary (2012) construction is defined as: “the clearing, dredging, excavating, grading of land and other activities associated with the realisation of buildings, structures or other types of real property such as bridges, dams and roads”.

In order to add onto the definition and to give the reader a better understanding of construction, a case study on public perceptions of construction engineering was investigated. This case study was a social research workshop conducted by The Royal Academy of Engineering and the Engineering and Technology Board jointly commissioned by the British Market Research Bureau (BMRB) and Social Research (Marshall, McClymont and Lucy Joyce, 2007). They conducted research exploring public attitudes to, and perceptions of, construction engineering and construction engineers (Marshall, et al., 2007). The aim of the research was to provide a baseline measurement of public knowledge and understanding of construction.

During their workshop on May 2007 in West London, it was found that out of 48 participants, 6 different worker types were identified in construction engineering. These types of engineers included the ‘middle aged boffin’; the ‘whiz’; the ‘designer’; the ‘mad scientist’; ‘Mr fix-it’ and ‘high-visibility-vest man’. The workers and their environment were described using words like “piles of paper”, “grubby looking man”, “dirty overalls”, “works outdoors ” and “wise” (Marshall, et al., 2007). This workshop also provided the basis of the perception that construction engineers are hardworking, pressured with work and not fazed by their appearance and paperwork (Marshall, et al., 2007).

Besides the stressful and cluttered environment, construction still functions as one of the most influential industries (Oxford Economics, 2011). This might be attributed to the fact that construction engineers regularly refer to past experiences when deciding on a method for doing tasks (Katz & Allen, 1985). Referring to the past is a phenomenon that is widely seen even with research and developers who need to come up with innovative ways of thinking (Katz & Allen, 1985). Katz and Allen (1985) stated that the urge to exchange uncertainty for more predictable work routines and consistent economical information delivery, decreases the receptiveness to change.

Evidence of this phenomenon is confirmed by Mattingly (2002) which states that the basics of constructing a house, hospital and basically anything else have stayed the same for centuries. This statement was complemented by Gil Whittenberg, the former owner of Whittenberg Construction, who said: “Just like we do today, the Egyptians also put one brick on the other when they laid brick.” (Mattingly, 2002). Wilson (2005) argues that construction techniques have become more sophisticated but changes after the early 1900’s were less radical than the changes the industry had seen during 1860-1920.

The slow evolution in the late 1900's and the referral to the past to dictate methods employed today create the perception that construction managers value historical methods and past experiences. Oltmann (2007) agrees that there is truth and value in previous experience, but past events have more value when they are analysed to identify what worked well and what needs to change. Oltmann (2007) did not provide information as to why, but mentioned that analyses by construction managers focus more on what worked and less on what needs to change.

In order to validate the above mentioned statements the tendering processes of a large established construction company in South Africa was investigated and it was found that, when faced with a similar problem or activity, contractors make use of financial compensations and use safety factors to correct mistakes made in the past (Jackson, 2013). This was to an extent a validation of Oltmann's (2007) statement and gives the impression that changes in construction are made incrementally or in small steps. No mention was made of method alterations or radical change.

African Business Research Ltd did research to determine the top 200 companies in Africa (Salami, 2007). It was found that the top four construction companies, based on market value, operating in South Africa are Aveng Ltd, Murray and Roberts Holdings, Wilson Bayly Holmes [Pty] Limited and Group Five Ltd. Correspondence with management of these companies made it clear that very little dedicated research is done, on company level, in the fields of identifying technologies to help develop new construction methods (Schonrock, 2013; Jackson, 2013; le Roux-Arries, 2013; Phenix, 2013)

A question one could ask is how there can be a lack of research into new construction methods when newer generation students are graduating annually from universities, technikons and Further Education and Training (FET) colleges in South Africa and go to work at these top construction firms? One could argue that these newly graduated workers might not have been challenged to think critically while studying, or that critical thinking was suppressed by other factors in the work environment. To explain why there could be a lack of adoption of input from younger workers in construction companies, an investigation was started to determine what the age distribution of engineers in South Africa looks like.

It is stated by Alyson Lawless in her publication "Numbers and Needs" that the industry has a huge age gap between experienced senior engineers and junior developing engineers (Lawless, 2007). This is complemented by Hewlett, Sherbin and Sumberg (2009) who state that the composition of the workforce comprises of two groups of individuals, namely the baby boomers and generation Y.

The term baby boomers refers to the large amount of older managers that are at retiring age. The generation Y refers to the group of people born from 1983 to 2004 (Howe & Strauss, 1992). In between these two age groups lies generation X which is estimated to be half the size of the other age groups

(Hewett, Sherbin, Sumberg, 2009). This means that the current younger generation needs to learn from the much older generation in a short space of time before the older generation retires (Hewlett, et al., 2009).

The significant age gap between experienced managers, young graduates and employees can have various effects, some of which could be attributing to the lack of acceptance of input from the younger work force. Work pressure is a term defined by Duanxiang (2009) as the emotional and physical reaction an employee has when placed in an important situation where he or she feels as if they do not have enough ability to solve the problem. Based on the statement of Hewlett *et al.* (2009) young engineers could therefore easily be exposed to work pressure from the more experienced engineers to make use of their tried and tested methods.

Digital literacy is another factor that was investigated in the search for reasons why younger workers are not fully utilized in terms of their knowledge of technology. Digital literacy is described by Eshet-Alkalai and Chajut (2010) as the ability of a user to operate and understand digital environments such as computers, digital cameras and modern cars. It is widely perceived that the younger generations have a better digital literacy, and this perception is verified by Eshet-Alkalai and Chajut (2010). The use of these skills and potential technological alternatives proposed by younger workers will, however, not necessarily be implemented by an established company with confidence. The reason it will not necessarily be implemented is due to the way in which new alternatives are chosen.

According to a number of managers in South African construction companies, new alternatives are considered during the pre-project phase of planning for the purpose of implementation within that specific project. The implementation of the alternatives often relies on the project managers' approval to take on the risk of implementing something new (Schonrock, 2013; Jackson, 2013; le Roux-Arries, 2013; Phenix, 2013; Egerton, 2013).

Engineering news journalist, Sashnee Moodley (2012) conducted an interview with the construction leader of KPMG Africa, Gavin Maile, who stressed that tight profit margins, as a result of competition in the industry, leave no room for error on major projects. This forces management to minimise risk and to rely on previously used methods. Work pressure is described by Duanxiang (2009) to have internal and external sources. Whether the source is external such as competition in the industry or internal to the company atmosphere, too much of this work pressure is bad (Duanxiang, 2009). Excessive work pressure can lead to serious reduction in work enthusiasm and efficiency (Duanxiang, 2009). The intimidation experienced by younger employees could, therefore, cause them to have a narrow-minded approach to problems due to the fear of failing and lack of enthusiasm.

Duncan Bonnett, a research partner at Whitehouse and Associates, stated in an interview with Engineering news journalist, Siyenza Management, that South African construction businesses are not utilizing opportunities because they are blindsided by the economic challenges within the country (Management, 2012).

One of the great challenges in the South African construction industry is the Expanded Public Works Programme (EPWP) that was launched in 2004. The EPWP appeals particularly to the infrastructure development industry to use labour intensive construction methods. This can be a reason why technological alternatives such as complex machinery are not being used to improve productivity of construction because of the fear of replacing labour and not abiding by the regulations of the EPWP.

A few possible reasons for slow adoption were discussed above, but the initial argument of slow adoption of technology in construction is further supported by Egbu, Bates and Botteril (2001). They proved that the worldwide construction industry is slow to recognise the benefits of information technology as a major tool beyond communication. Hendrickson and Au (2008) also argue that although there are definitely technological improvements in construction, the rate at which technology is used to aid construction is slow relative to other industries. The slow adoption of technology and perceptions of a stressful and cluttered environment with incremental changes contributes to the overall impression of the construction industry.

In this section it was also identified that the age gap, digital literacy and the way in which decisions are made in construction companies of South Africa can contribute to the lack of technology investments. Given this background in construction, it now remains to be seen how the manufacturing industry functions in order to ascertain if there are lessons to be learned that can be used in the construction industry.

1.1.1.2 Manufacturing and the voluntary adoption of technology

Manufacturing, on the other hand, is defined by the Business dictionary (2012), as: “the conversion of components, raw materials or parts into finished goods.” Manufacturing makes use of a man-machine setup with division of labour in large scale production. Division of labour is further defined as where labourers have a narrow specialisation with regards to the tasks in a production line. This enables the labourer to work faster on the task due to repetition and skills development while conquering the challenges of the task.

In contrast to construction, manufacturing brings to mind elements such as robotic arms, computer aided drawings, consistent precision, production lines and mass production. Here, labour is used to manage and operate highly advanced mechanical processes to create an end result. If one looks at the automotive manufacturing industry it is clear that the driving factor for many motor vehicle companies is safety and quality (Toyota, 2011) (ASTM Standards, 2012). The focus on safety and quality stems from the demands of the users of the cars.

Constant research is done within the automotive industry to satisfy the highly demanding needs of the user (Ettlie, 1998). Dedicated research and development (R&D) divisions are used to create the competitive edge in terms of newer and better products for the user (Ettlie, 1998). Cars seem to be developing at a rapid pace in terms of technology, and the manufacturing of automobile parts has to develop accordingly in order to keep up (Ettlie, 1998).

The concept of trial and error might be the biggest difference between the construction and automobile industries. In construction only one product is built and there is hardly a project drawing that can be used for a second time without adjustments. Unlike the construction industry, the manufacturing industry spends time and effort in producing many prototypes to eventually come up with a winning product (Brockmann & Birkholz, 2007). This is done in conjunction with R&D within the different manufacturing companies.

The automobile industry is Europe's largest investor in R&D and has an estimated investment value of €20bn (The Automotive Council, 2010). Eight of the top 25 R&D investors in the world are vehicle and parts manufacturing companies (Godwin, 2009). This investment into R&D drives the industry forward and helps to deliver more sustainable motoring (Godwin, 2009).

Automobile manufacturers are willing to invest time and money on research and development, because this secures long term competitiveness. Jürgen Leohold, the executive director of Group Research at Volkswagen, mentioned in his opening presentation at the annual conference of the European Council for Automotive R&D (EUCAR) that innovation must be accelerated especially given the current global financial situation (Godwin, 2009).

Henry Ford and the production of the model T automobile proved that the manufacturing industry has, to a large extent, managed to optimise time, cost, quality and risks when technology-aided methods are used. Ford used to manufacture cars by hand until the introduction of the model T and the production line (du Preez, et al., 2010).

Ford introduced the concept of manufacturing cars with the aid of a production line in order to generate more profit in a shorter time (du Preez, et al., 2010). The assembly line, together with other organisational changes, gave rise to the fact that assembly time dropped from 12.5 hours to 93 minutes, and that prices decreased from $850 in 1908 to $440 in 1915 (Georgano, 1973). Ford's factory achieved this by developing technology-aided production lines which proved to be a more efficient and reliable way of producing quality products in large quantities (Georgano, 1973).

In the automotive industry, technology was seen to be the answer to profitability issues and the high demands of the user (Georgano, 1973). According to the African Economic Outlook (AEO), new technology is improving service efficiency, education quality and is cutting the costs of doing business (African Economic Outlook, 2013). The manufacturing industry has thus utilized technology to improve time efficiency, cost effectiveness and quality standards.

Given the information about the manufacturing industry it can be deduced that technology is used together with labour during manufacturing and that this combination managed to improve the cost and time effectiveness of production without compromising on quality or increasing risk. Manufacturing also showed a bigger investment value into R&D and still wants to increase R&D to keep up with user demands and to ensure long-term competitiveness.

1.1.1.3 Summary of construction versus manufacturing

In summary, section 1.1.1.1 discussed construction, and it was perceived as a stressful environment with a high possibility of experiencing work pressure. This work pressure can cause the younger generation workers to have a lower work performance and motivational level. The major age gap, the industries' competitive nature and the way in which new methods are chosen for implementation add to the reason why research into technological aided construction is possibly not undertaken to the same extent as within other industries. Manufacturing on the other hand was seen to have a research and development mind-set due to the high user demands and the increased demand for quality and safety. R&D is also done in manufacturing to increase the long-term competitiveness of companies.

Overall it seems as if the manufacturing industry has a bigger incentive to develop in terms of technology than the construction industry. This is confirmed by Brockmann & Birkholz (2007) in their publication of industry and culture of construction versus manufacturing.

It is hard to understand why there is a vast difference between manufacturing and construction when both aim to construct or produce a product from materials and other parts. It is, however, made clear by Brockmann & Birkholz (2007) that the structure, culture and environment of the two industries are almost opposite to each other. This can be seen in Table 1.1 which is a summary of the conclusions made by Brockmann & Birkholz in their study.

However, given the difference in the structure, culture and the environment of manufacturing and construction, the advances and benefits that R&D provided in terms of technology for the manufacturing industry, cannot be denied. Therefore this background comparative analysis inspired the current research study to investigate the possibilities that technology could provide to the construction industry.

Table 1.1 - Comparison of construction and automobile industry (Brockmann & Birkholz, 2007)

Construction industry	Automobile industry
Environment	
Higher labour intensity	Lower labour intensity
Lower material intensity	Higher material intensity
Lower plant intensity	Higher plant intensity
Site production	Assembly line production
Mechanized production	Automated production
Discontinuous production	Continuous production
Unit production	Mass production
Structure	
Fewer levels of management	More levels of management
Not formalized	Formalized
Decentralized	Centralized
Much verbal communication	Little verbal communication
Organic structure	Mechanistic structure
Culture	
Not well defined	Well defined
Highly communicative	Little communication
Result oriented	Process oriented
Professional	Organizational
Pragmatic	Normative

1.1.2 Development of technology in South Africa

The second area of literature that forms part of the inspiration of this research topic is the technological development of South Africa. It was stated earlier that the realisation of the benefits technology provided the manufacturing industry served as a reason to investigate the technological development in South Africa.

At the World Economic Forum meeting on 28 January 2001, various presidents from around Africa committed to the Millennium Africa Renaissance Program (World economic forum, 2001). This program states the intent of the African leaders to commit to the sustainable and economic development of Africa. Two of the six priorities on the action plan were to invest into Information and

Communication Technology (ICT) as well as in infrastructure. This statement further justifies research on the use of technology and combining it with research on the construction industry in order to develop infrastructure.

The ICT Indaba held in Cape Town from 4 to 7 June 2012 served as a call to African delegates to set up a continental policy and to expand the growth of the ICT industry in Africa (ICT Indaba, 2012). Other objectives of the conference were to showcase new technology within the ICT sector and to create better international alliances to encourage knowledge transfer. As a result, the ICT Indaba aimed to optimally and appropriately use technology to increase the performance of six key sectors of which business and infrastructure are prioritised as the first two (ICT Indaba, 2012). This aim of the ICT indaba directly supports the argument that construction companies, as major role players in infrastructure development, should incorporate ICT in an appropriate and optimal way.

The conference was held in response to the realisation that Africa and South Africa are lacking in adopting ICT in these important sectors. This statement is supported by OSEC (2011) in the terms of reference document published by the committee of the ICT Indaba (2012) prior to the conference. This document states that South Africa, as a country, is the 20th largest user of ICT products in the world (OSEC, 2011). However, most of the products used in South Africa are imported, because the research and development thereof is not emphasized or supported well enough in Africa (OSEC, 2011). The ICT sector of South Africa has shown to come second to comparable counterparts in terms of growth. Moreover, the growth in ICT in South Africa has dropped from 4% in 2005 to 1.4% in 2009 (OSEC, 2011).

The Knowledge Economy Index (KEI) is a summative figure calculated on a country's economic incentive regime, innovation, education and ICT development. The composition of the KEI can be seen in Figure 1.1. According to the World Bank's Knowledge Assessment Methodology (KAM), South Africa's KEI has dropped with 15 positions from 2000 to 2012. This puts South Africa in 67st position from 146 other economies globally, and among the top 10 countries with the largest drop of KEI ratings in the world (World bank , 2012). Over and above the KEI Index, the Economist Intelligence Unit Limited (2011) rated South Africa 47th from 66 countries in terms of their overall information technology industry competitiveness index. This index comprises of different sections and weights as seen in Table 1.2. South Africa was rated 51st in the IT infrastructure division, 37th in Research and development and 36th in Support for IT industry development (The Economist Intelligence Unit Limited, 2011).

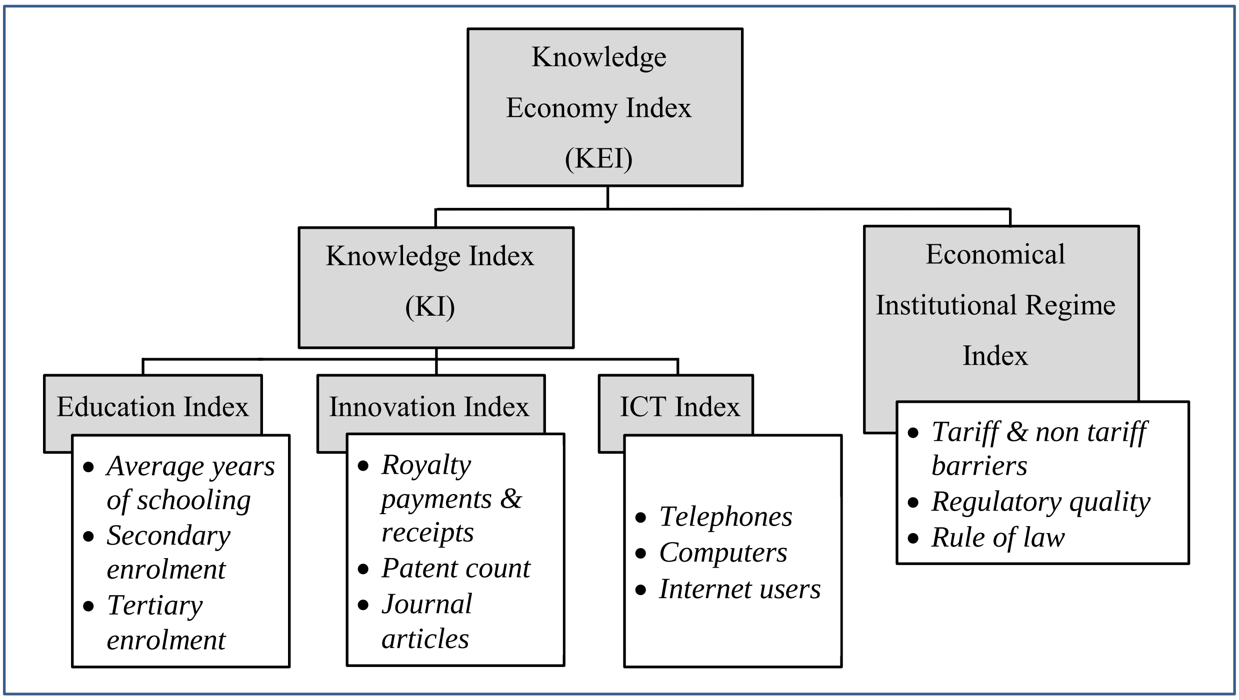

Figure 1.1 - Diagram explaining the composition of the Knowledge Economy Index KEI (World Bank, 2012).

Table 1.2 - IT industry competitiveness index categories and their weights (The Economist Intelligence Unit Limited, 2011).

Category	Weight
Overall business environment	10%
IT infrastructure	20%
Human capital	20%
Legal environment	10%
R&D environment	25%
Support for IT industry development	15%

All of the mentioned statistics and ratings reveal the potential for improvement in terms of technology in Africa and South Africa. Various factors influence the development of technology and "developing country" is an encompassing term that could be used to explain why South Africa is not competing as well with the rest of the world. An investigation was therefore done to determine whether being regarded as a developing country could explain why South Arica has had a declining growth rate in terms of KEI.

A developing country can be defined as a country that has not yet been developed to full extent and can also be classified as underdeveloped (The American Heritage, 2005). The World Bank classifies countries in terms of their Gross National Income (GNI) per capita per year. Countries with a GNI of

US$ 11,905 and less in 2010 are defined as a developing country (World Bank, 2012). Most of these underdeveloped countries are in Africa, Asia and Latin America (The American Heritage, 2005). With South Africa classified by various authors as a developing country, systems should be in place to encourage growth in different sectors such as technology usage (World Bank, 2012; Holtz, 2008; Education and Training Unit, 2010). Therefore, being a developing country does not provide an adequate reason to explain why South Africa has a declining growth rate in terms of KEI.

The state of technology developments in South Africa was seen as another motivation to investigate technology investments in South Africa. Being regarded as a developing country was seen to be an invalid reason to explain the lack of technology investment and this was rightly realised by delegates who attended the ICT conference. Furthermore, because many influential delegates committed to the further investment of technology and infrastructure, decision making with regards to technology investments in infrastructure development was seen as an important aspect to investigate.

1.1.3 Summary of inspiration for the research thesis

Together, the two broad streams of literature reviewed, namely the comparison of manufacturing and construction and the technology developments in South Africa, provided enough evidence to support the relevance of investigating technology investment in construction. Given the intent of various African delegates to invest into technology and infrastructure, a process that can assist the decision-making of technology investments was seen as a research field that demands attention.

1.2 Problem Statement

Given the background provided of construction versus manufacturing and the state of technology development in South Africa, the major question that will be discussed in this research thesis is as follows:

What process should construction companies follow in order to make informed decisions, with regards to investment in technology, to solve the current areas of concern?

A *process* refers to specific actions or steps that should be taken, in a sequence, in order to have a specific end result (Oxford Dicionaries, 2013). Based on the commitments of the ICT delegates to promote technology in business and infrastructure, *construction companies* were identified as the area within which research will be conducted. *Informed decisions* refer to decisions that considered a reasonable amount of accurate information from sources that show experience or knowledge about the situation (Oxford Dicionaries, 2013). *Investments in technology* refer to the attainment of technology to be incorporated in the way business is done within a company. The goal of the process and the decisions on investments are to improve the way business is done. This is done by *solving areas* that are *of concern* to the business which keep the company from performing optimally.

1.3. Research Objectives

The main objectives of this research study are to test one hypothesis and answer six relating research questions. While answering the research questions, a specific area of concern will be identified and used to establish a process that could assist technology investment decisions. After the hypothesis is tested and the questions are discussed, contractors will be able to use the process developed by this research to assist the decision making processes with regards to technology investments. These technological investments should ideally be made to address problematic areas and thus help to improve the problem solving processes. In this way technology can aid in solving some of the areas of concern that keep companies from operating optimally. If contractors experience the same area of concern used as an example in this research, they will be able to use more of the research to improve that specific problem.

1.3.1 Hypothesis to be tested:

1.) A generic and flexible process can be formulated to assist construction companies in making decisions with regards to technological investments.

1.3.2 Related questions to be discussed:

a) Are there any generic areas of concern in the different divisions of civil engineering construction?
b) What is the most influential area of concern in the South African construction industry?
c) What aspects of this area of concern can be improved on?
d) What technology can be used to address this area of concern?
e) How will the effects of the technology be quantified in terms of cost versus benefit?
f) Can technology be used to improve a problem solving process of construction companies?

1.4 Research Methodology

This research thesis was performed by completing the following six steps:

- Step 1: Perform background study
- Step 2: Define problem statement to be discussed
- Step 3: Define scope of investigations
- Step 4: Perform literature study
- Step 5: Discuss questions identified in the research objectives
- Step 6: Prove hypothesis identified in the research objectives

1.4.1 Perform background study

An initial background study was done by investigating two areas of literature namely the difference in manufacturing to construction and the technological developments in South Africa. The purpose of this background study was to inspire further research and validate the relevance of the topic of this research thesis. The study provided valuable insight into the difference between manufacturing and construction as well as information on the current state of technology in South Africa. This was used to formulate a problem statement. The material used for this background study included books, the internet, journal articles, engineering articles from magazines and dictionaries.

1.4.2 Define problem statement to be discussed

Defining the problem statement was done by considering the way forward, given the realisations that came from the background study. The literature provided evidence that there is a need to invest in technology and that infrastructure development is a high priority in the development strategy of Africa and South Africa. Furthermore, the benefits that technology has given manufacturing, as well as the relatively slow development of technology in construction, provided reason to investigate technology investments in construction. The need to invest in infrastructure and technology for development was evident and decision making regarding these investments proved inevitable. For this reason the problem statement included the question of identifying the correct process for making decisions, specifically regarding technology investments in construction. These technology investments should address some problem or area of concern identified within the company or industry.

1.4.3 Define scope of investigations

Defining the scope of the investigations was started by investigating the construction industry. It was quickly found that the economies and construction industries of different countries differ and it is difficult to envisage how technology will influence the different construction industries world-wide. Also, South Africa has shown to be behind in technology developments when compared to many other countries. For these two reasons the South African construction industry became the focus of the investigation.

The driving force of the construction industry is construction projects, and for that reason projects were analysed (Schalcher, 2008). The construction industry is described by Schalcher (2008) as complex with construction projects having many role-players and phases. These role-players and phases were therefore investigated to gain understanding of the factors that have an influence on a construction project.

While construction projects were considered, it was found that a large portion of the total project-costs is incurred in the operations phase. This is illustrated in Figure 1.2 showing the cost and resources allocated during the life span of a project (Project Management Institute, 2008). The operations phase is where the implementation-planning, scheduling of construction and physical construction takes place. These tasks are largely managed by contractors and construction companies. For this reason, this study investigated how this phase can be optimized by the contractor.

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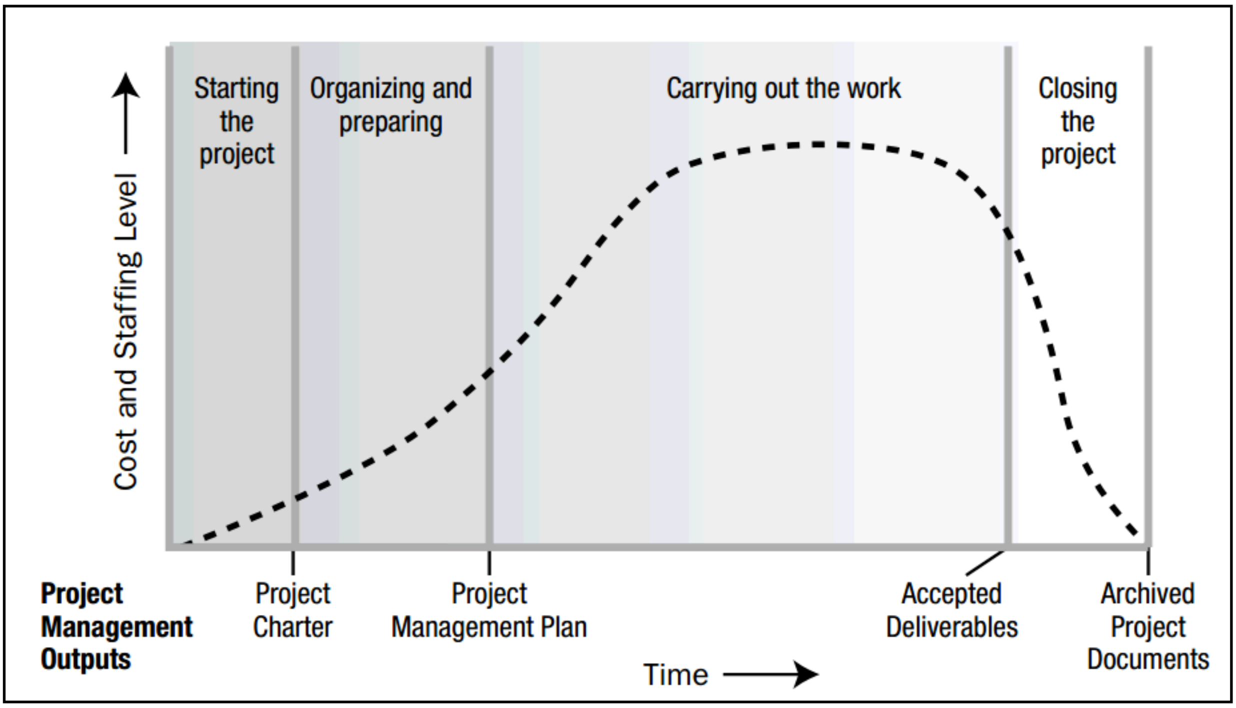

Figure 1.2 - Typical cost and staffing levels across the construction project life cycle (Project Management Institute, 2008).

After investigating the phases of construction of the different divisions of civil construction, it was seen that, although the phases of construction are generic, the tasks are performed differently within the different divisions. Literature showed that various companies and institutions divide civil work into different divisions such as geotechnical, structural, water and transport. The different civil divisions showed similarities but had different ways of performing the different phases of a project.

At this stage of the scope definition, the purpose of the research was revisited to ensure congruency between the research method and research objectives. It was found that this research was initiated to improve aspects of construction. Rummler and Brache (1995) as well as Coleman and Endsley (1999) have stated that the identification and solving of problematic areas are part of the first steps to improvement. For this reason the research included the identification of problematic areas within the different divisions of civil construction. Given the similarity of phases and that emphasis will be placed on the operations phase, areas of concern were identified within the divisions to see if there are similar concerns.

Whether there are generic areas of concern in the different divisions of civil construction was a question that was stated in the research objectives. This supported the necessity of incorporating an investigation into the different areas of concern experienced in the different divisions. The most influential area of concern, within the scope of the investigation, needed to be identified so that this could be used as a vehicle to establish a problem solving process. This research would then be evidence to show how such an area of concern can be addressed within a process that assists technology investments. Factors influencing this area of concern formed part of the research scope so that it could form the basis of areas of improvement.

When the management of a company needs to decide whether or not to acquire new technology, they need to be convinced of the benefits of such a change. For this reason it needs to be demonstrated that the acquisition of technology will be of value to the company both now and in the near future. The scope of the research was therefore inclusive of investigations into different decision making models and how they work. Finally the discussion of the recommendations and findings was also included into the scope of the investigation to give the reader a comprehensive and well concluded research thesis

1.4.4 Perform literature study

A literature study was performed on the structure of the construction industry and the technological innovation in construction. Material used in support of the arguments included books, internet sources, peer reviewed journal articles, and engineering articles from magazines and dictionary definitions. The review of literature on the structure of the construction industry formed part of the initial scope definition of the current study and was performed to provide a holistic background and theoretical foundation to the remainder of the research process.

The section of the literature study about the technological innovation in construction elaborated on the findings of the background study that was done to inspire the research and determine the relevance of the research topic. This section of the literature study further describes the state of technological developments in construction and gives the reader background information about the reason why companies change. Furthermore, possible reasons why technological developments are relatively slower in construction were also discussed.

1.4.5 Discuss questions identified in the research objectives

The purpose of the study was to determine which process construction companies should follow to make informed decisions when considering investment in technology. In order to investigate such a process, this study identified a problem and then solved it. This approach was used as an example of a process, and formed the case study from which the research in this paper identified a proposed process for deciding on technology investments. This research process was assisted by answering research questions and the research process is described in the following paragraphs.

The discussion of the questions identified in the research objectives form the most significant part of the research thesis. This part of the research was done after the review of literature was completed and a broad knowledge base was established. Just as with the other steps of the research methodology, the discussions of the questions were supported by various sources, viz. books, internet sources, peer reviewed journal articles, engineering articles from magazines and dictionaries.

The first two questions under the research objectives were discussed in order to identify a generic area of concern in construction that can be used as a case study to establish the technology investment process.

Interviews were arranged with managers that have experience in one or more divisions of civil engineering and are working in South African construction companies. These managers were utilized to screen the large amount of areas of concern within civil construction. This was done by providing them with a large list of possible areas of concern that were identified in the review of literature. These areas of concern were then rated in terms of relevance and significance so that they could be ranked. A second step was taken to identify a single area of concern, using questionnaires as part of a survey. The survey was conducted in two phases. The first phase was conducted to screen and rate the areas of concern with more specific variables. The second phase of the survey was aimed at obtaining more information about the most influential areas of concern identified in the first phase. The interviewers, as well as the respondents of the survey, had a substantial amount of experience and all held managerial positions which validated the information as expert opinions. The fact that a generic area of concern was selected adds value to the case study, allowing for more divisions of civil engineering to potentially benefit from the solution provided.

The purpose of the third question under the research objectives was to further investigate the area of concern so that the best solution can be given and that informed decisions can be made regarding the improvement of that area of concern. This investigation involved reading relevant references and synthesising their findings.

The fourth question was discussed to investigate the possibility of already existing technology that could be utilized to address an area of concern specific to construction. Relevant references were used to support the chosen technologies.

The purpose of the discussion of the fifth question under the research objectives was to identify a way in which companies can assess themselves. This assessment involves determining to what extent the proposed technology will have overall beneficial effects on the company. This was done by incorporating a multi criteria decision model that aims to help decision makers to quantify relevant advantages and disadvantages.

The purpose of the discussion of the sixth question was to prove that technology could have benefits beyond just decision making but could assist in data capturing, measuring and other phases of a problem solving process. This was done by identifying a problem solving process that related to the problem identified. Each of the steps within this process was investigated to see if technology could improve the steps of the process and ultimately the entire process.

1.4.6 Prove hypothesis identified in the research objectives

The final step was to test the hypothesis that was derived from the research objectives. The discussions of the questions that were identified in the research objectives aided in testing the hypothesis. This hypothesis was discussed to illustrate, to construction companies, the possibility of structuring technological decision making in an understandable and quantifiable manner.

1.5 Structure of the research

The structure of this research will be directed by the elements recommended for inclusion by Siddiqui (2007) in a feasibility study. This structure follows a logical flow in which the present organisational system, different solutions and pros and cons are carefully investigated. This structure provided a good flow in which the problem statement and the research objectives could be discussed. The discussion of the hypothesis and questions identified in the research objectives are also incorporated into this structure. Siddiqui (2007) identified eight essential elements as listed in Table 1.3 for ease of reference.

Table 1.3 - Elements that should be investigated in a feasibility study (Siddiqui, 2007).

Element	Chapter	Description
1	1,2,	The present organizational system
2	2	Stakeholders, users, functions, objectives
3	3	Areas of concern with the present system
4	4,5	Inconsistencies, inadequacies in functionality, performance policies
5	6	Possible solution alternatives
6	7	Different levels/types of the solutions
7	7	Different business processes for solving the problems
8	8	Advantages and disadvantages of the alternatives

1.5.1 The present organizational system:

The first element entails summarising the current organizational system. This element requires the task of doing a literature review to understand the size, way of operation and scope of the fields investigated. This task was performed in Chapter 1 and Chapter2.

In Chapter 1 of this research, a general introduction is given to the research. This involves a background study which forms the inspiration of the research and also provides information about the current state of construction and technology development in South Africa. The problem statement, methodology as well as the research objectives that were set out to achieve are also given in this chapter.

In Chapter 2 a composition of the construction industry is provided as well as information on the existence of innovation and Research and Development (R&D) in construction. Construction projects are investigated as part of the construction industry. Construction projects are the driving force of the construction industry and are analysed in terms of the role-players involved and the phases in its life cycle. The different divisions within civil construction are explained due to the fact that the operations of these divisions differ.

Chapter 2 also gives further background of the reasons and factors that cause companies to change. Also included in this chapter is a comprehensive investigation into the current state of innovation, technology and research and development within construction.

1.5.2 Stakeholders, users, functions, objectives:

The second element that should be considered in a feasibility study involves identifying the stakeholders and role-players in the current organisation. In Chapter 2 the tasks of the role-players are given and role descriptions are provided to clarify their function within the project. Chapter 2 also mentions the different construction and engineering societies or bodies involved with research and/or development. The function of technology and R&D is also explained in Chapter 2.

1.5.3 Areas of concern with the present system:

It was through a literature study in Chapter 3 that a large amount of areas of concern in construction were identified and this action therefore represents the 3rd element of a feasibility study. To make these areas of concern specific to the South African scope of investigation, these problems were rated by managers established within companies in the South African construction industry. Further effort was made to identify the most influential area of concern by analysing responses to two questionnaires sent to a group of experienced construction managers working in the South African industry. The calculations and the results are explained prior to identifying the most influential area of concern as rated by the experienced construction managers through the survey.

1.5.4 Inconsistencies, inadequacies in functionality, performance policies:

The most influential area of concern is analysed and discussed in Chapter 4 and Chapter 5. This area of concern, therefore, represents the inconsistencies, inadequacies in functionality and lower performance as described by the 4th element of a feasibility study. The policies regulating this concern are also described and investigated.

1.5.5 Possible solution alternatives:

Element 5 of a feasibility study is concerned with the possible solutions to the problematic areas. In Chapter 6 the identification of problem areas was discussed and possible solution alternatives for the given problem were proposed.

1.5.6 Different levels/types of solutions:

Chapter 7 describes how the effects of possible solutions can be seen on different levels. These levels are identified and a method of measuring and evaluating the effects of the solutions on various levels is described. This discussion represents the inclusion of the 6th element of a feasibility study into this research thesis.

1.5.7 Different business processes for solving the problems:

Chapter 7 also describes the process of using multi criteria decision models to solve problems. These models make use of different criteria and team members to rank solution alternatives. These team members are normally representatives of different levels of the business. The different categories of criteria are representative of the different business processes a company needs to consider as required by element 7 of a feasibility study. These criteria, therefore, play a big role when making decisions on whether or not to implement the proposed solutions.

1.5.8 Advantages and disadvantages of the alternatives:

Chapter 8, describes the last element of a feasibility study — the research findings section. This section of the paper considers the advantages and disadvantages of the proposed solutions to the problem statement. A discussion on the hypothesis is given while referring to the discussions of the questions identified within the research objectives.

CHAPTER 2

Literature study

This chapter provides an overview of the literature on the key concepts and theories relating to the current study.

Within this chapter a broad background is given with regards to the construction industry. This is done by giving an overview of the size of the industry and other indicators. The different role-players involved with construction projects are mentioned and each of these role-players' general responsibilities are discussed. Another purpose of this chapter is to give a background on the current state of innovation and development in construction. The reasons why companies change as well as the existence of R&D will be discussed, after which technology is defined and contextualised.

2.1 Structure of the construction industry

In this section the construction industry is discussed in order to provide the magnitude of the impact the industry has and to explain the involvement of its resources. By giving background to construction, this section can be used as a reference when construction concepts are referred to later in this document. The role-players of a construction project are identified and their roles are described. The different phases of a construction project are investigated and specific tasks that need to be performed are identified at each phase. Furthermore the different divisions in civil engineering construction are identified as obtained from different literature sources and different names of the divisions are compared between different sources of literature.

2.1.1 Construction Overview

The construction industry is one of the biggest and fastest growing industries worldwide and global construction is expected to grow by almost 70% from $7.2 trillion today to almost $12 trillion, ten years from now (Oxford Economics, 2011). The contribution of this industry to the Global Gross Domestic Product (GGDP) is 10% and accounts for 40% of energy and fuel consumed. Construction also uses up to 50% of all resources over the globe (Economy Watch, 2010).

The construction industry is regarded as a conglomerate of industries that plays a vital role in the economy of a country while it adds value to the built environment (Gounden, 2000). Furthermore Gouden (2000) identifies the following contributing factors of the construction industry:

- The production of specific, national and basic needs in the form of infrastructure;

- The provision of most of a country's fixed capital assets and infrastructure, thereby playing a pivotal role in national development and generating the necessary infrastructure to enable other industrial sectors to develop;
- A direct contribution to the country's Gross Domestic Product, thereby stimulating further growth through its linkages with other industrial sectors;
- The creation of employment opportunities.

Taking the magnitude and importance of the construction industry into account it can be said with confidence that investigation into ways to optimise construction projects in South Africa is of great value to the economy, the society and the environment.

Figure 2.1 illustrates the focus areas of the civil construction industry that are covered in this section. The different divisions shown in the picture are the selected divisions which were based on definitions from different sources of literature. How these divisions were selected will be explained in section 2.1.4. Besides highlighting the focus areas, the illustration also shows the order in which they are discussed in this thesis. The illustration also represents how each of the focus areas ties into each other within the construction industry.

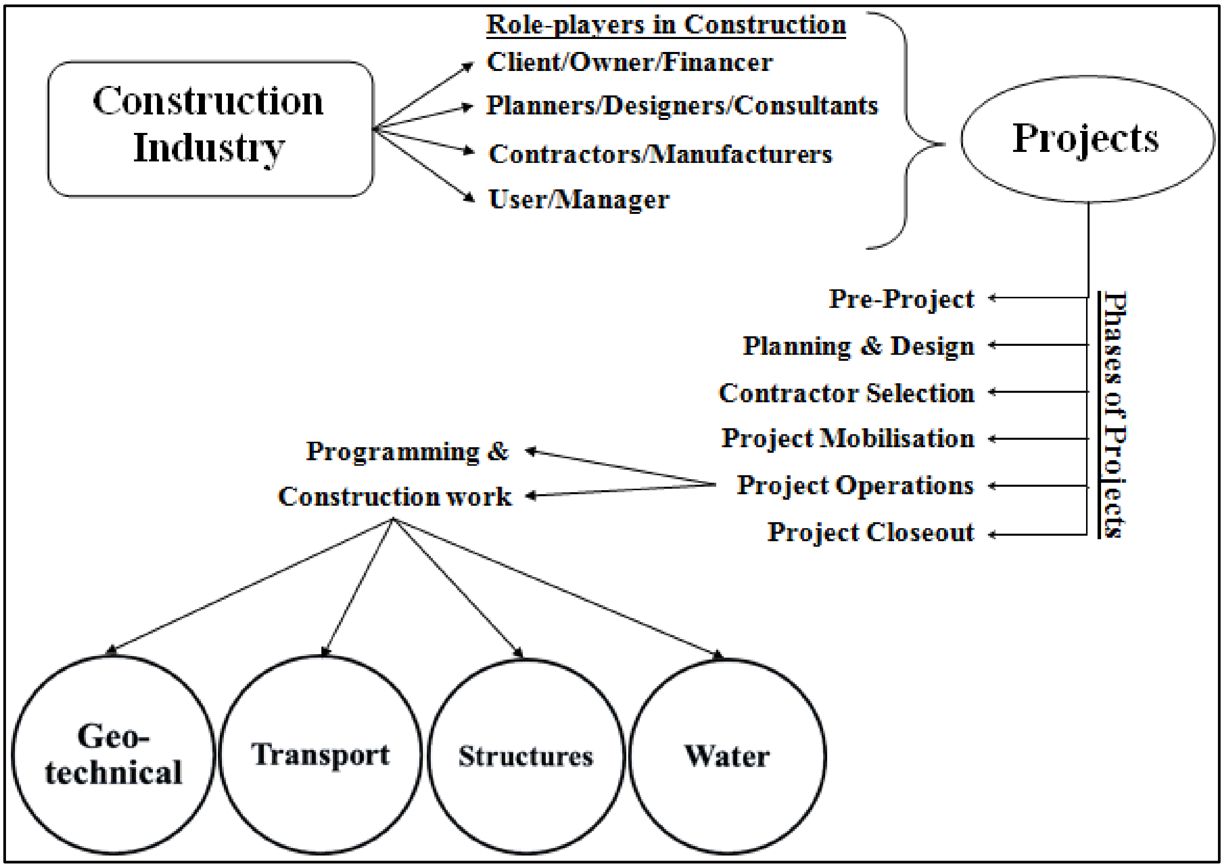

Figure 2.1 - Schematic representation of the focus areas within the construction industry.

2.1.2 Role-players in the construction industry

There are different role-players in the construction industry each of them having an important role to ensure that a project performs well. According to Wessels (1986) the client and designer can have up to a 75% influence on the total project cost, if they were involved in the preconstruction phases of the project. It is therefore important to consider these role-players when trying to optimise construction projects. It is also critical to make the relationship between these parties of such a nature that they complement each other (Wessels, 1986). The different role-players that have a direct influence on construction projects can be seen in Figure 2.2.

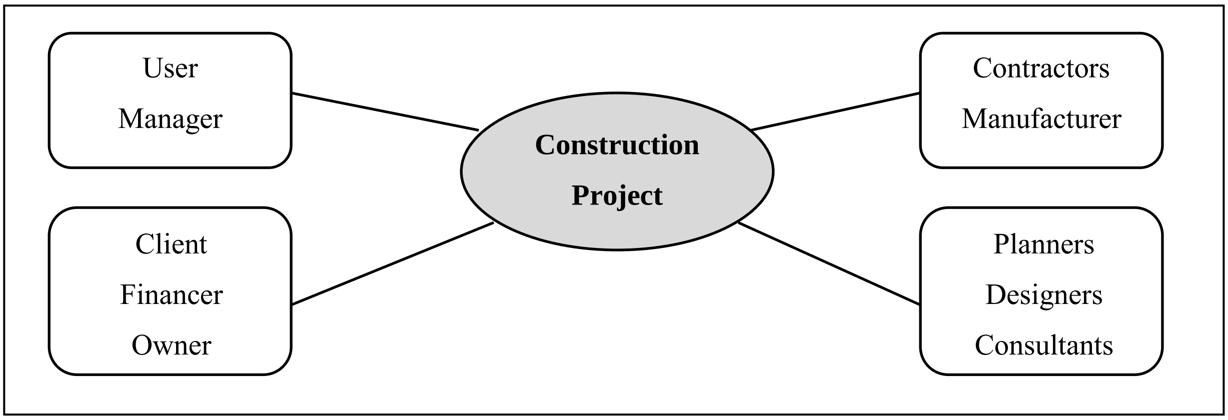

Figure 2.2 - Role-players directly influencing a construction project.

The role played by the client, financer or owner is that of project initiation, financing and, in some instances, maintenance of the end result. The planners, designers or consultants are responsible for designing, coordinating and supervising the project. Contractors or manufacturers are in charge of the actual construction of the design and management of the construction process. The user or manager of the end result is responsible for maintenance and support services. Given these roles, it seems that construction projects are generally straightforward but, in actual fact, this is not the case. These responsibilities, as stipulated above, are rarely as clearly defined and often the roles are integrated. Different people are responsible for different tasks in each new project.

The success of projects relies on good relationships and communication between the role-players. Consequently careful thought has to be put into any factors that cause unnecessary friction and disputes (Wessels, 1986). If one could reduce factors that cause negativity, it could have a big effect on the success of a project. The interaction between the different role-players in a construction project is not the same within the different stages of a project. If one uses the traditional procurement method used in South Africa for example, the contractors' first involvement in the project is when they tender for the construction of the project, while they are not involved in the planning phase. This implies that at different stages of the project, focus must be placed on the nurturing of different relationships between the role-players.

2.1.3 Phases of construction projects

The construction industry is project based, and projects in general form the connection that links the different role-players. Whether a project is big or small, it comprises of six main stages. These stages are set out in the life cycle of a project shown in Figure 2.3 and are described in the following sections.

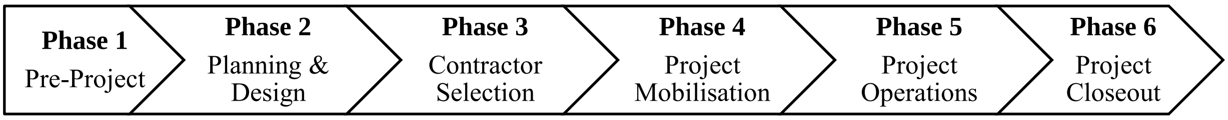

Figure 2.3 - Construction project life cycle (Egeland, 2009)

2.1.3.1 Pre-project phase

The start of a construction project generally originates from an idea or a need to improve the capacity of something (Egeland, 2009). This idea leads to a feasibility study done either internally by in-house resources or externally by chosen specialists (Egeland, 2009). The internal evaluation of a project often considers the profitability of the project by taking into account the availability of funds and own resources. External tests are objective and are regulated by trends within the industry such as market changes and the results of sustainability movements such as the Conference of Parties (COP).

The owner of the project has to make a decision on the project delivery method and this is done in conjunction with the feasibility study (Egeland, 2009). According to Kenig (2011) project delivery is defined as the method by which a project is contracted for construction. This will thus determine the procurement method and whether there will be a professional designer or consultant that will help to appoint a contractor. Building contracts in South Africa usually make use of the Joint Building Contracts Committee (JBCC) form of contract which supports the method of appointing a designer prior to construction tendering (Joint Building Contracts Committee Inc, 2007). Procuring in this way is referred to as the traditional procurement method (Richards, et al., 2005). Another delivery system uses only one entity that is responsible for the execution of the project concept. A public private partnership is an example of a delivery system where one private entity is responsible to realize and often finance projects for the public sector. The decision of procurement method is based on the client's requirements. These could include the requirement of completion within budget, on time or simply getting the best value for money. (Watermeyer, et al., 2003).

Besides choosing the feasibility tests and project delivery system, the owner also has to decide on a contract type early in the project. This decision is made based on the outcomes of the feasibility study and the chosen project delivery system. There are many different standard contract templates that are used in South Africa. Standard contract forms such as the FIDIC (French acronym for International Federation of Consulting Engineers) 1999, General Conditions of Contract for Construction Works

(GCC 2004), JBCC Series 2000 and New Engineering Contract (NEC) family of standard contracts, are contracts that the construction industry development board (CIDB) recommend (Construction industry development board, 2005).

These conditions of contracts, which are chosen by the client, clarify who takes on which risk and also stipulate how the contractor will be paid. The client or owner will also have to decide how the design professional will be paid for his services and whether the designer will be representing the client during the execution of the operations phase. Depending on the experience of the owner in administrating projects, he might appoint a professional engineer, architect or project manager to provide advice on the decisions during the pre-project phase (Egeland, 2009).

2.1.3.2 Planning and design phase

During the planning and design phase the project scope is clearly defined and the necessary documentation is prepared for contractor selection. In order for this to happen the respective parties involved in this phase have to complete tasks in three different stages. The first stage involves defining the project objectives, then considering alternative ways to achieve these objectives and finally determining if the project is financially feasible. This first stage also involves developing a project brief, program statement, preliminary cost estimate and getting the necessary public input. Based on the results of the first stage of the planning and design phase a final decision will be made to continue with the planning of the project (Egeland, 2009).

During the second stage of the planning and design phase, the design professional will perform a detailed design. The detailed design involves optimizing the size, material and interaction between the components using advanced theory of loads and behaviour. The contract documentation is also prepared during the planning and design phase and will be used by the different contractors to develop their construction strategy. The final contract documents submitted by the design professional not only consist of detailed drawings but also contain legal requirements and technical specifications that specify the materials and the way in which the components should be installed (Egeland, 2009).

2.1.3.3 Contractor selection phase

When choosing a contractor the client or owner can decide between issuing an open invitation in public papers and if only specific contractors will be invited to tender.

Contractors on the other hand have to decide whether or not they will be tendering for the project. If they do decide to tender, they need to perform a number of tasks according to the specifications of the client. These tasks usually include preparing a method statement and describing the types of plant that will be used. The contractor also has to submit a preliminary project program and a priced proposal. The priced proposal will include the cost of labour, materials, subcontractors and various overhead charges that will be added to calculate the profit.

After submittal of the tender proposals, prices are announced and the client or owner has to choose between the tenderers. After choosing a tenderer, price negotiations may take place and the final construction contract will be finalized which will state the chosen contractor (Egeland, 2009).

2.1.3.4 Project mobilization phase

Prior to the commencement of work by the selected contractor various tasks must be performed. These tasks include the fortifying of bonds, licenses and insurances and the preparation of a detailed program for construction activities. The project budget needs to be finalised in this phase and is done by taking the cost estimate and turning it into a project budget. Together with the finalisation of the project budget, a system for tracking the actual project costs must be established (Egeland, 2009).

Site establishment must make provision for temporary buildings, access roads, storage and security if necessary. The process of procuring equipment and materials needs to be initiated and provisions should be made for labour on site. Once these tasks have been performed, the actual construction can start on the instruction of the client (Egeland, 2009).

2.1.3.5 Project operations phase

This phase of the project is where the client has given the selected contractor the right to start with the planned work as set out in the scope of works. The scope of works needs to be approved by the client and the contractor and will form part of the contract documentation. The tasks of the contractor, who will perform the actual construction and planning thereof, will be classified into three areas: monitoring and control, resource management and documentation and communication and can be seen in Figure 2.4.

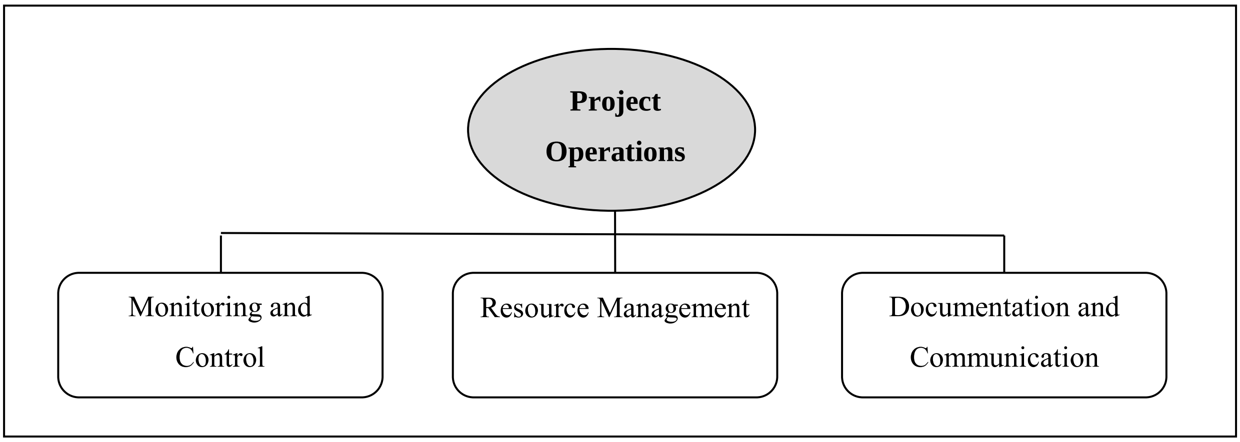

Figure 2.4 - Three areas of the project operations phase (Egeland, 2009).

When considering the area of monitoring and control, as part of project operations, there are various tasks the contractor needs to do, the first of which is to constantly compare the actual progress to the planned program. If the project is not on schedule, then actions must be undertaken to make up for lost time.

It is important that the contractor reports progress on a regular basis to the client. This will prove to be valuable information during possible disputes. The cost status should also be monitored just as the program status is monitored. This will help to compare actual expenditure to the budgeted amounts (Egeland, 2009).

The client often makes use of a quality clerk, also known as a clerk of works (COW), to monitor the quality of work. Depending on the size of the project, the COW could be resident on site. It is thus to the benefit of contractors to utilize the COW to ensure that rework of phases are kept at a minimum. The contractor normally has to abide by specific regulations over and above the regulations agreed upon in the client contractor contract. Such regulations include worker safety on site and environmental regulations during and after the operations phase.

Resource management is the second area where the contractor has to give attention to. This involves assigning and supervising personnel so that they perform and reach the given targets (Egeland, 2009). A big part of resource management and especially labour management is controlling and managing the productivity of labourers on site. This has proven to be a big problem in construction projects in South Africa (Bothma, 2012). Plant and materials also need to be managed according to the program, because excess material on site is a risk for the contractor, as is the availability of materials needed to stay on schedule.

Another area which the contractor has to deal with is effective documentation and communication (Egeland, 2009). Site diaries are an important aspect in terms of documentation and should be kept by the contractors' workforce as well as the resident engineer on site. Documenting in a site diary becomes valuable information used in claims for weather delays and other issues that may cause disputes.

Construction projects generally have large amounts of paperwork and special effort is required to manage this effectively (Bauer, et al., 2006). Approval documents that require the signature of the client and or owner are some of the documents that may cause time delays if no compensation is made for delays. The need to frequently respond to requests for change in the project amounts to complications and paperwork during operations (Egeland, 2009). Quantity surveyors also have their hands full when it comes to determining and documenting the amount of work done. Claims need to be submitted timeously to ensure that the cash flow of the project is still in a good state. On-line and other electronic means are available to manage some of the paperwork electronically to assist the contractor with project communications (Egeland, 2009).

The project operation phase can be executed differently with regards to the way in which the tasks in the three areas are done. These different approaches are seen when assessing the different fields of work within the civil construction industry. These differences are mainly caused by different construction methods that are used in different fields of work (Bothma, 2012) (Jackson, 2013) (Farber, 2012) (Passmore, 2012).

2.1.3.6 Project closeout and termination phase

The final stage of a construction project involves the termination and closeout phase of the project. Before the contractor’s responsibilities are complete a number of tasks need to take place (Egeland, 2009). With certain infrastructure projects such as dam walls, test runs need to be performed and start-up tasks need to be done. Final clean-up and remedial work that may result needs to be done prior to practical completion can be granted to the contractor (Jackson, 2013).

This phase of the project also includes site disestablishment and termination of the employee’s contracts. Paperwork to finalize the last retention money to be paid needs to be approved and as-build drawings need to be submitted and archived by the contractor (Egeland, 2009). A closeout meeting is good practice to identify lessons learned and evaluate the ease of work of the different stages of construction (Egeland, 2009).

2.1.4 Divisions within the civil construction framework

Figure 2.1 in section 2.1.1 shows that arrows point in different directions to different divisions of civil engineering construction. The reason for this is because even though programming and construction work are tasks that all divisions of civil engineering implement, they implement them in different ways. Apart from the different implementation of the same tasks in the different divisions, different names are given by different institutions for the divisions in civil engineering construction. For these reasons an investigation was done to define the different divisions in civil engineering construction and to specify what will be investigated in these different divisions.

While investigating the broader scope of civil engineering it was found that it is hard to define divisions of civil engineering that exclude the fields of work of other divisions. For instance, environmental engineering and project management are both very different fields of work and would be defined by some as different divisions of civil engineering, yet both are universal to construction engineering in general. Structural engineering, as a division, also finds a way into every other division because almost any civil construction, whether it is a dam or a bridge, involves the construction of a structure.

Literature shows that there are different names of divisions describing the different fields of work within the civil engineering industry. However when looking at the scope covered within the different divisions of each reference, the total scope of the civil engineering industry has many resemblances across the board. Table 2.1 shows the different names and divisions as defined by different references investigated (South African Institution of Civil Engineering, 2011; Canadian Society for Civil Engineers, 2006; Stellenbosch University, 2006). Construction companies also have different ways of grouping their divisions within the business and have specific fields of work done within these divisions (WBO, 2011; Aveng Grinaker-LTA, 2013; Murray and Roberts, 2013

The varying results regarding the names and grouping of different fields of work into divisions, created an incentive to make use of one set of division names and clearly define what fields of work are included within those divisions.

Table 2.1 - The civil engineering divisions as defined by different references (South African Institution of Civil Engineering, 2011; Canadian Society for Civil Engineers, 2006; University of Stellenbosch, 2011).

	References		
	South African Institution of Civil Engineering (SAICE)	**Canadian Society for Civil Engineers (CSCE)**	**Stellenbosch University**
Divisions	Water	Coastal	Geotechnical and Transport
	Transportation	Structural	Structural and Informatics
	Railway and Harbour	Materials	Water and Environmental
	Project Management	Project management	Construction and Engineering Management
	Structural	Transportation	
	Geotechnical	Environmental	
		Water resources	
		Geotechnical	

A simplified structure of the divisions of civil engineering and construction was created based on the structure of one of the biggest construction firms in South Africa. The reason for this was because the main problem areas of specific construction methods within this company were identified as a preliminary step taken to identify major problems in the construction industry. A manager from each of the divisions in the company was chosen to provide information about that division. Given that the divisions of the company will be similar to the divisions of the civil engineering structure created from different reference, each manager can be regarded as an expert in one of the divisions of civil engineering construction. These managers provided information on the problem areas and the construction methods used within these divisions. Taking this into account, the different divisions chosen to define the structure of the civil engineering construction industry are listed in Table 2.2.

Table 2.2 - Civil engineering divisions and descriptions as per this study.

Division	Description
Geotechnical	Within this division investigations take place on ground technologies and stability structures that are used to ensure reliability of ground conditions under specific loads.
Structural	This division covers material-theory, informatics, modelling and high rise structures such as buildings and power plant chimneys and lift shafts.
Water	The water division covers issues such as coastal water systems and structures, water reticulation, water retaining structures and water purification and treatment.
Transport	Transportation deals with bridges, intersections, railroads and layered pavement structures.

With the different fields of work divided into these divisions, the investigation was started by interviewing the different managers. This was seen as an effective way to investigate methods used and to identify practical aspects of each division.

2.1.5 Summary of the structure of the construction industry

In summary, section 2.1 provided a summarised explanation of how the different elements of the construction industry work and tie into each other. The definition of different divisions of the civil engineering industry provided the structure to identify generic problematic areas within the industry of South Africa. The method used to identify the areas of concern in the different divisions will be explained in detail in Chapter 3.

2.2 Technological innovation and development in construction

In the previous section, focus was on the existing structure of the construction industry and the different elements it comprises of. In this section investigation will be done with regards to the state of technology, innovation and development within construction.

The construction industry has changed drastically in the past few years and has become much more competitive (Adrian, 2013). The tight economic times has caused those who want to survive in this industry to look at ways of competing effectively (Kim, 2001). One of the ways to achieve corporate success is to be able to adapt to a quick changing environment (Kim, 2001). As stated in section 1.1.1 the manufacturing industry has benefitted tremendously from technology-aided methods and hence produces products with lower unit costs, shorter construction time and less risk whilst having a focus on better quality. It was therefore seen as relevant to investigate what sort of developments exists, in terms of technology, in the civil construction sector.

This section investigates the important role of technology and why enterprises change. It also investigates the existence of technology research and development in South African construction and the different ways subcontractors and large contractors go about technology research.

2.2.1 Why companies change

The term enterprise engineering is defined by du Preez *et al.* (2010) as the discipline concerning the design and re-design of an enterprise. This involves looking at problem areas and finding solutions fitted for the specific problem. It is also regarded as the mechanism that provides structure to the change cycle synonymous with changes.

Within each company there is an inherent need to have the preferred product or to be the preferred service provider. This achievement is described as having the competitive advantage (du Preez, et al., 2010). Given the constant change of the demand of the user or client, companies are forced to produce even better products with higher quality. Organizations which do not recognize the impact of various innovations and have not adapted to changing environments have justifiably been forced out of the mainstream of construction activities (Hendrickson & Au, 2008). Enterprise engineering is regarded by Du Preez *et al.* (2010) as inevitable. However, even though the process seems inevitable, there are factors such as the high demands of the customer and financial feasibility, which force companies to pro-actively practise enterprise engineering. According to du Preez *et al.* (2010) factors such as these can be classified into internal and external drivers of change and these will be discussed in the following sections.

2.2.1.1 External drivers of change

There are four main external drivers of change and these include customer expectations, competition, regulations and technology. These external drivers of change will now be discussed.

2.2.1.1.1 Expectations of the customer

Due to the fact that different companies try to gain the competitive advantage over other companies, the customer is getting exposed to ever increasing higher standards of service delivery and quality. This in turn forces the companies to produce products that, at least, match the expectation of the customer. Du Preez *et al.* (2010) states that it is not required that a company predicts what the customer will demand in years to come, but that the company has the mechanisms and ability to adapt to the changing expectations.

2.2.1.1.2 Competition

In the struggle to gain or keep a competitive advantage over the competitors, improvements made by other companies will also be assessed and are likely to be mimicked by other companies (du Preez, et al., 2010).

2.2.1.1.3 Regulations

Legislation and best practice policies, especially with regards to environmental regulations, drastically influence the processes of a company and could force them to change (du Preez, et al., 2010).

2.2.1.1.4 Technology

Changes or advances in technology can compel a company to adopt the new technology in their company. Evidence of this phenomenon can be seen in the example of the United Kingdom (UK) construction strategy that recognized the improvements of Building Information Modelling (BIM) and introduced it as a prerequisite to bidding in the UK (Cabinet Office UK, 2012).

2.2.1.2 Internal drivers of change

There are three main internal drivers of change which include complexity, financial and product change. These drivers of change will be discussed in the following sections.

2.2.1.2.1 Complexity

Expansions of the company in different branches or even making the company international, creates complexities in the implementation of policies, processes and other facets of the business (du Preez, et al., 2010). In order to stay a good functioning company some changes have to be implemented to compensate for the expansion of the company. Complexity can be an internal driver of change due to the urge to remain competitive given that the delivery of services has become more complex.

2.2.1.2.2 Financial

Having to make a product more affordable or delivering a product or service with better efficiency to reduce overheads can force a company to change (du Preez, et al., 2010).

2.2.1.2.3 Product changes

The changes of products are dictated by external factors such as technology, competition and changing customer expectations. These changes in products lead to changes internally with regards to the processes, and delivering of a product or service.

2.2.1.3 Summary of why companies change

From this section it is seen that changes occur because of many different reasons. Factors contributing to change are called drivers of change and include external and internal drivers. It was seen that technology is a phrase that is used in some of the drivers of change. The attainment of technology is not easily done because of the complexity of technology investment decisions. In Chapter 7 the evaluation of technology alternatives are discussed together with a short literature review on decision models used for technology attainment. The next sections will define and explain the importance of technology in society.

2.2.2 Defining technology

Earlier in this research paper, mention was made of technology and how technology could be used to solve some of the problematic factors within a specific construction problem. Before the possible technological solutions and the feasibility thereof are evaluated, it is necessary to define what we mean by technology.

According to van Wyk (2002), technology is a term commonly used to describe a set of different aspects ranging from software and computers to the totality of tools invented by humankind. A popular view of technology is that it has an inherent complexity and that it comprises of a large number of separate fields, each with its own terminology and characteristics. Van Wyk (2002) defined technology as follows:

> *Technology is created competence. It is expressed in technological entities consisting of devices, procedures, and acquired human skills.*

The word *created* in the definition refers to the fact that technology is artificial and it does not exist spontaneously in nature. *Competence* emphasises that technology is focused on the means or the way of taking action and not the ends of doing so. *Technological entities* refer to the measurable unit that can be evaluated. Technological entities can therefore be visualised as a collection or a repository of competencies or ways of taking action. The *devices, procedures and acquired skills* are the elements that an entity comprises of. The hardware and software components are explained by devices and procedures respectively. Human skills refer to the involvement of human skills in the creation of the technology. Present human skills are not part of technology as an entity but human skills are required to create the technological entity (van Wyk, 2002).

Given this broad definition of technology and technological entities, van Wyk (2002) still mentions that technology is often differentiated by descriptive predecessors. Examples include information technology, Global Positioning System (GPS) technology and communication technology. These groups of technological entities are therefore classified based on the function it has or assists.

This research paper will investigate technologies included in the areas of information and communication technology, GPS technology as well as software programs that integrate the benefits of these two groups of technological entities.

2.2.3 Importance of Technology

In this emerging economy, information technology and the collection of knowledge and experience is one of the most powerful weapons a company can have. According to Rasli *et al.*(2004) information technology (IT) is considered as one of the critical factors of effective knowledge management.

Many practitioners and researchers have mentioned that the incorporation of IT with knowledge is important to support project performance (Rasli, et al., 2004).

As stated by du Preez *et al.* (2010) and Love, Irani and Edwards (2004), technology is a driver of change, and is often used by competitors to gain a competitive advantage. For this reason technology can be regarded as an important and powerful tool and worth investigating. If investigation produces evidence that technology can have similar positive effects as showed in manufacturing, technology could prove to be an integral tool to improving the productivity of companies in other industries. These investigations will however be discussed in later sections of this thesis.

Given the potential benefits technology can provide, the next step of this investigation is to investigate how well technology is researched in terms of the use thereof in construction.

2.2.4 Existence of R&D in construction

In the automobile industry it is often seen that different forms of technology are used and incorporated into the manufacturing and functioning of the product. Examples include manufacturing robotic arms, which help in manufacturing the product (Harris, 2002) and close proximity sensors which benefits the functionality of the product (Volkswagen, 2013). Another phenomenon that is present in R&D in the automotive industry is the cooperation with other firms and institutions in order to exceed the in-house innovation capacity and thus utilizing external resources (Wolfgang & Jürgen, 2004). In other words the

R&D departments in the automobile industry are using existing technology and resources and incorporate it to have a remarkable effect on the manufacturing and functionality of the final product.

This means that in order for cars to be able to develop as rapidly as they are, research is not only done by the specific car manufacturing company. Private entrepreneurs or researchers are also asked to do specific research to develop individual pieces of technology on a contracted basis (Ulset, 1996). This means that manufacturing and other industries realise the importance of R&D. They also go to great lengths to gain knowledge and outsource R&D to other specialist companies if their in-house resources are not sufficient (Ulset, 1996).

As shown in the above statements, R&D is used by other industries to utilise existing technology in a beneficial way. This helps to advance both the companies incorporating R&D and the industry. The problem is that R&D and the use of technology is not being incorporated in construction as fast as in other industries (Hendrickson & Au, 2008).

In order to support this statement of Hendrickson and Au, further investigation was done into four different areas. The first two areas investigated innovation and technology as well as the boards and associations responsible for development of the construction industry. These two areas were investigated to understand what is meant by innovation and technology and if the boards, which focus on the development of construction, are focusing on technological innovation and R&D. The last two areas investigated, focused on the educational structure for innovation and also how South Africa compares to the rest of the world in the fields of technological innovation and R&D. The latter two areas were investigated to understand how innovation is stimulated within the educational structure and how South Africa's R&D compares to the rest of the world.

2.2.4.1 Innovation and technology

When looking at the etymological origin of the word, innovation only describes something new (du Preez, et al., 2010). Newness, however, is only part of the definition of the innovation and should therefore not be associated with invention. Contrary to an innovation, an invention does not have to be a success or economically viable. Innovation is therefore defined by Katz (2007) as follows:

> *The successful generation, development and implementation of new and novel ideas, which introduce new products, processes and/or strategies to a company or enhance current products, processes and/or strategies leading to commercial success and possible market leadership and creating value for stakeholders, driving economic growth and improving standards of living.*

The major difference between innovation and invention lies in the sense that innovation is derived when an invention was used and utilized to ensure commercial success (du Preez, et al., 2010). It is innovations and not inventions that are seen as important for survival of businesses in the ever demanding commercial environment (du Preez, et al., 2010).

Innovation stems from two triggers, namely market-pull and technology-push. Market-pull is caused by increased demands from the customer as the customer gets used to higher standards and norms. Technology-push is seen as radical innovation and often fulfils an unknown need of the customer. These are two very different triggers of innovation and are not to be seen as the only drivers of innovation. In Figure 2.5 numerous internal and external factors can be seen that put pressure on companies to search for solutions through innovation.

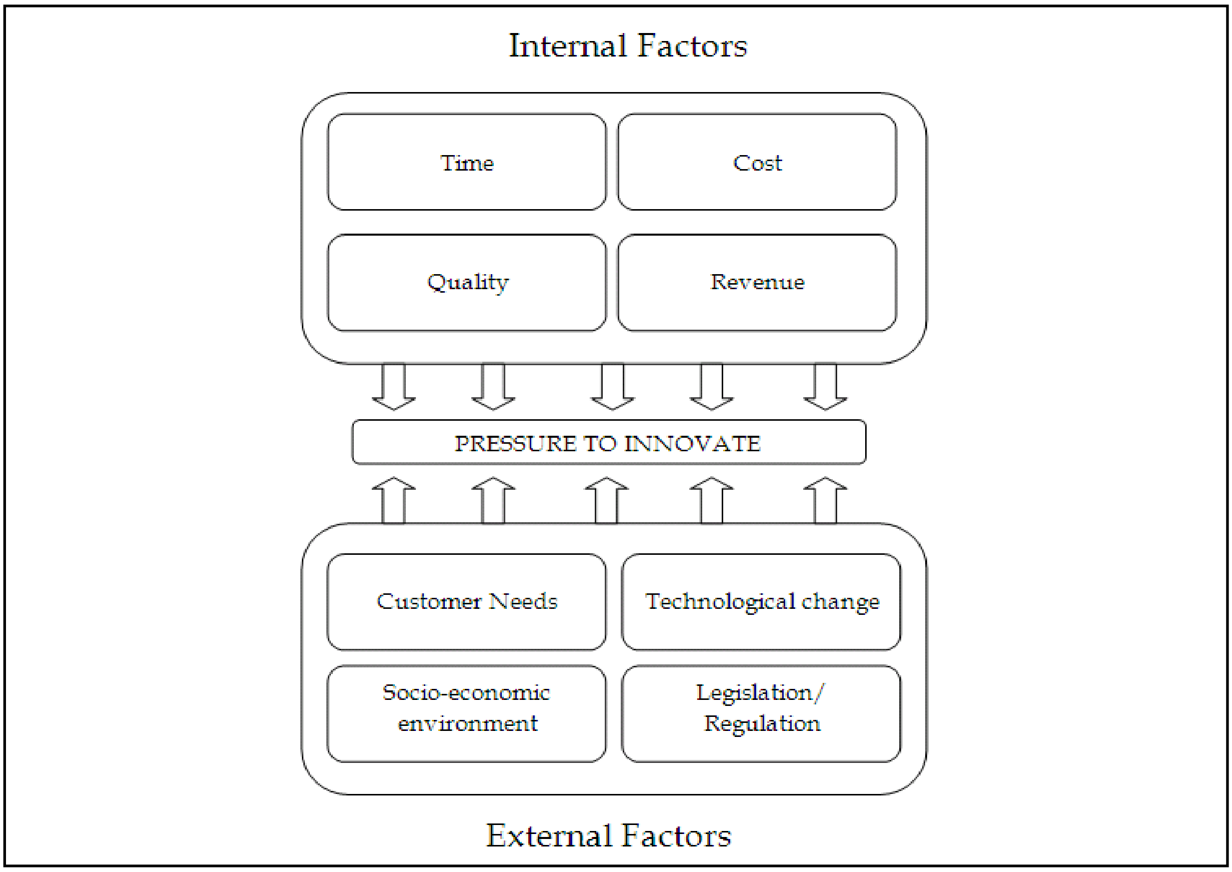

Figure 2.5 - Internal and external factors pressuring innovation (du Preez, *et al.*, 2010)

Employers in the private sector said that the most intense pressures for change were cost-based, and the most common response to such pressures was product innovation and marketing (du Preez, et al., 2010). Management in the public sector cited new technologies and equality and diversity in the workplace among the greatest internal pressures for change. One of the major external factors for change was budget constraints (European Foundation for the Improvement of Living and Working Conditions, 2007)

Without R&D one of the external factors of change,viz. technological change can become a blind spot to companies striving to be competitive. This statement is confirmed by van Wyk (2002) who states that most corporate managers admit to being blindsided by new technology. This could be due to the fact that there is no fundamental structure by which technology can be managed due to the definition of technology (van Wyk, 2002). It is rare to find a CEO of a company who systematically maps global technology and therefore knows where to expect definitive developments (van Wyk, 2002).

However the pressuring factors are often not enough to ensure that a successful innovation is created. The basis of innovation remains a broad knowledge base gained by research (du Preez, et al., 2010). Figure 2.6 is a representation of the knowledge supply chain that describes different modes of research and the role-players involved in providing funding and knowledge. This schematic representation is similar to the findings of Mayer (2001) and they have many similarities in terms of the logic of the process.

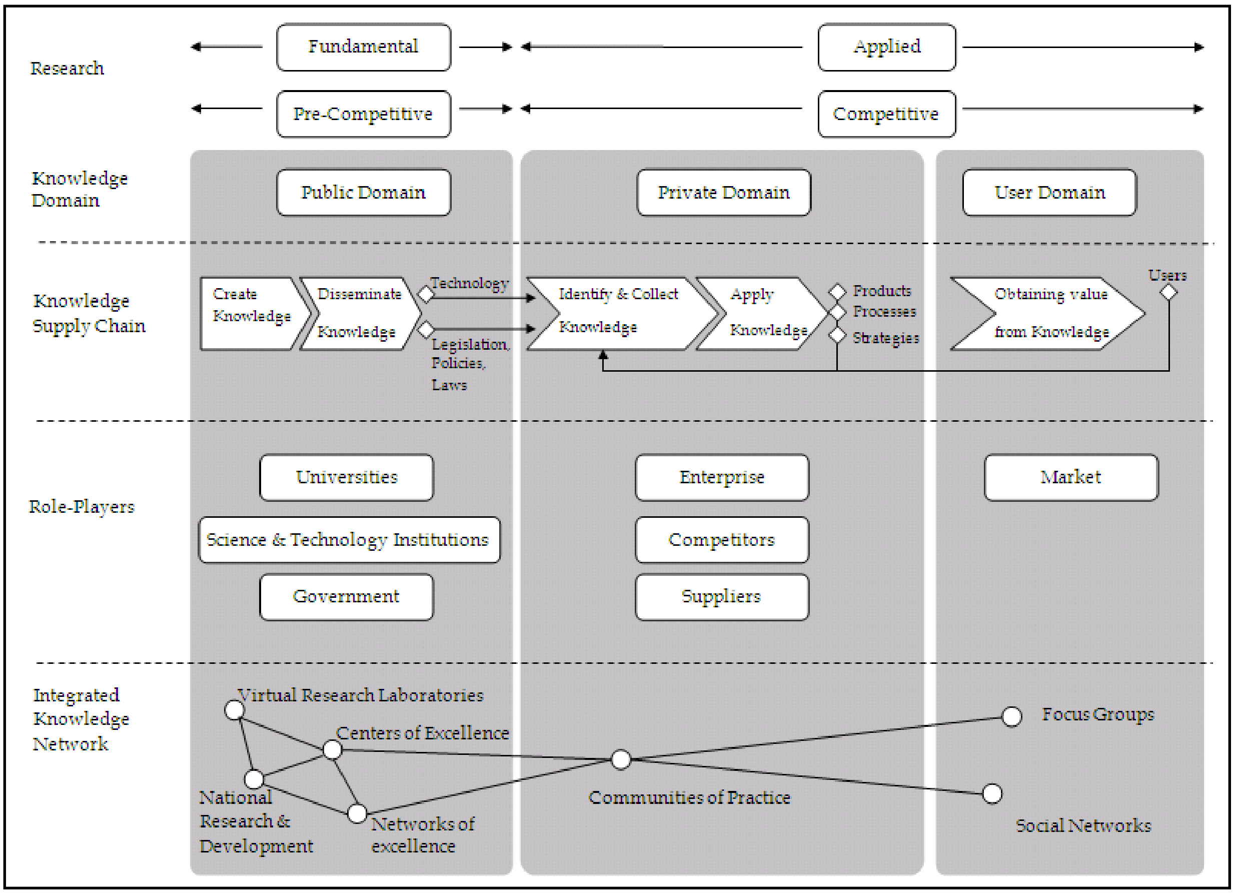

Figure 2.6 - The knowledge supply chain (Du Preez & Louw, 2007).

When looking at Figure 2.6, distinction is made between two modes of research. These two modes differ with regards to who does and funds the research and in what domain the research is implemented. Fundamental research is normally done by universities and funded by the government and/or other pre-competitive research institutions that are part of the public domain (Du Preez & Louw, 2007).

Fundamental research is the mode that contributes to the basis on which new technology and innovation is built on (du Preez, et al., 2010). The results from this mode of research need some improvement from the second mode of research,viz. applied research, to have a noticeable impact on the company's competitiveness (du Preez, et al., 2010).

Knowledge of technology, legislation, policies and laws is used by the private domain as part of their applied research. The know-how needed prior to the application of the knowledge, stems from the user domain (Du Preez & Louw, 2007). This is good proof as to why various domains and role-players are involved in good innovations that work. In order to manage the flow of knowledge, an integrated knowledge network is needed. This statement is complemented by Wolfgang and Jürgen (2004) who stated that collaboration and outsourcing during R&D ensure a more effective innovation process.

In this section technology and innovation was defined to get an understanding of the two concepts. Given this understanding, an investigation was done to see whether the existing boards and institutions, focused on development of the construction industry, incorporate technological innovation and R&D into their development strategies. The investigation of the different boards and institutions is discussed in the following section.

2.2.4.2 Boards or institutions dedicated to development of South African Construction

Holistically, the civil engineering industry in South Africa has a number of boards and institutions that address areas of concern across the industry. Examples of these institutions include the Engineering Council of South Africa (ECSA), South African Institution of Civil Engineering (SAICE), Construction Industry Development Board (CIDB) and South African Federation of Civil Engineering Contractors (SAFCEC). These boards and institutions were investigated to see whether they incorporate technological innovation and R&D in their development strategy.

2.2.4.2.1 ECSA:

ECSA (Engineering Council of South Africa) is a statutory body that is in partnership with the state and the engineering profession. This body aims to promote a high level of education and training for practitioners to encourage professionalism in the engineering profession (Engineering Council Of South Africa, 2012). ECSA has full autonomy, about who gets registration rights, but has an obligation to the interests of the state, profession and the public in terms of transparency (Engineering Council Of South Africa, 2012).

ECSA also recognises the progressive feedback and involvement of other societies such as the boards and institutions mentioned later in this section. ECSA (2012) says that these societies ensure that the public interest is taken into account in the development of the profession. ECSA is focused on creating a strong, competent and growing engineering profession in South Africa. This profession is sought after in order to have a positive influence on the country as a whole and to ensure that local capacity is striving towards the international norm (Engineering Council Of South Africa, 2012).

Growth of the profession happens through effective partnering with various stakeholders. These stakeholders include recognised Voluntary Associations (VA's), National and International Institutions/Societies/Associations, the Built Environment, Education Providers, Skills Education Training Authorities (SETA's) and National Government. ECSA is seen as the governing body and the boards and institutions that they support form part of their developmental strategy. The boards and institutions form part of the recognised stakeholders identified by ECSA and can be found on their website (Engineering Council Of South Africa, 2012). Not all of the stakeholders identified by ECSA are however focused on the development of the construction industry. Some of the stakeholders that are specifically focused on construction development in South Africa are investigated below.

2.2.4.2.2 SAICE:

SAICE (South African Institution of Civil Engineering) is an institution with an approximate member count of 10 000 individuals. The institution consists of corporate members and non-corporate members. The corporate members consist of honorary fellows, fellows and industry members. Non-corporate members consist of associate members and student members. The member distribution is thus diverse and comprises of individuals with varying work fields and experience in civil engineering (SAICE, 2011).

SAICE strives to be an institution that is educated and focuses on enabling its members to provide economical and environmentally sustainable infrastructure (SAICE, 2011). This is achieved by consultation and having an effective communication channel between the members and the stable institution. In order to improve the input and knowledge-base of the industry and the SAICE members, training and development courses are facilitated by experienced individuals organised by the institution (SAICE, 2011).

SAICE is involved with the professional registration process of civil engineers (SAICE, 2011). The institution gives suggestions about how to write essays that form part of the registration process, and provides topics to write about. They also facilitate many courses that focus on continued professional development of engineers. SAICE shows a strong interest in recognition and awards. Awards are given on an annual basis and strive to promote the art of civil engineering, promote and recognise success in the profession and protect the interests of its members (SAICE, 2011). Awards are given to individuals or groups and organisations that show outstanding performance in terms of advancing technology, teaching and research and engineering construction or management (SAICE, 2011).

SAICE focuses on being a knowledge and development partner that provides its members with continued education in technical, managerial and communication skills whilst assisting in the development of technical guidelines and documentation. Although education is an important aspect of innovative thinking these focus areas show no signs of innovation or technology research. The education and training is based on the already existing knowledge in the industry.

2.2.4.2.3 CIDB:

The CIDB (Construction Industry Development Board) is a public entity and was established in 2000 to promote a framework that is of a regulatory and developmental nature (CIDB, 2013). Public and private individuals make up the members of the board. These members are selected by the minister of public works based on their experience and knowledge gained in the industry. According to the CIDB the legacy of Apartheid left the construction industry with serious developmental and transformation challenges (CIDB, 2013). It is for this reason that the focus of the CIDB is construction capacity development and also growth that is sustainable. Improved performance and best practise are other focus areas of the board (CIDB, 2013). The board recognises ethical procurement processes and delivering enhanced value as important and therefore made these common focus areas of the board (CIDB, 2013).

The mandate of the CIDB includes the establishment of a register of contractors and projects so that the performance of the industry can be monitored and regulated for sustainable development (CIDB, 2013). Embedded into the mission of the board is the aim to develop and empower small, medium and macro enterprises within the industry (CIDB, 2013). Being closely associated with the minister of public works and the government, the CIDB issues publications with the public sector's approval. Registers are made public on their website which also tracks the grading, distributions and number of contractors in the country (CIDB, 2013). The CIDB also makes a list of tender opportunities and current projects that are running which is available for download on their website (CIDB, 2013).

The CIDB further focuses on assisting contractors to register and acquire a CIDB rating and also assist them with delivery management (CIDB, 2013). By making international standards of procurement available the board shows that it has the vision of developing South African contractors to an international standard. Various industry guides and other publications form the basis on which the CIDB helps to develop the industry. These publications include tips on marketing, cash flow management and whether or not to make decisions based on industry surveys (CIDB, 2011). While investigating these publications one of these surveys published showed evidence of investments. On further investigation the surveys showed that larger contractors and construction companies that have high CIDB ratings continue to invest in equipment to manage the higher work load and to be able to accept more work (CIDB, 2011). This statement gives the impression that investment is needed for development and growth of construction companies (CIDB, 2011). These surveys did, however, not make specific mention of technology and innovation. These two topics remain to be investigated at a later stage in this thesis.

Overall, the CIDB is a dynamic development board, focused on capacity building and best practise guidelines. The successes of established companies are recognised as the main developmental tool to uplift small construction companies. This organisation does not integrate with the education systems and does not show to have invested interest in innovation and technology developments.

2.2.4.2.4 SAFCEC:

SAFCEC (South African Federation of Civil Engineering Contractors) has been in existence since 1939 and is an employers' organisation (SAFCEC, 2012). Given this early origin, SAFCEC has made it a priority to adapt to the changing construction environment. In 1996 it became the national representative for civil engineering contractors. Being the national representative of more than 450 member organisations, SAFCEC also represents the members at government functions (SAFCEC, 2012). Embedded in their vision is their endeavour to be the leading construction industry representative body in South Africa (SAFCEC, 2012). SAFCEC states on their website that they are one of the biggest contributors to developing infrastructure in South Africa. This is attributed to the regional member committees that provide SAFCEC members with ample opportunities nation-wide. These opportunities involve the participation of members in industry related matters and decision making processes (SAFCEC, 2012).

SAFCEC has a track record of influencing policies and regulatory change and representing the interests of its members (SAFCEC, 2012). The organisation plays an integral part in the formulation of industry policies to ensure that legal documents and regulations do not hinder fair business practices. Given its representative power, SAFCEC also facilitates member participation in issues such as wage rates, conditions of basic employment and other matters of mutual interest (SAFCEC, 2012).

Part of the strategy of the organisation is to grow the skills pool of the industry. This is done by active participation in the curriculum of Further Education and Training colleges and other Department of Higher Education initiatives (SAFCEC, 2012). A unified training plan was developed that helps to define the roles and careers of specific employees such as technicians, foremen, supervisors and leaders. SAFCEC also has a Diamond Academy that trains member emerging enterprises through mentorship in order for them to become the next generation industry leaders (SAFCEC, 2012). Currently the Diamond Academy initiative is driven by established construction companies. The initiative does not focus on development in terms of innovation but rather acquiring skills mastered by the mentor company.

The strategy of this organisation is to represent the civil engineering contractors of South Africa and give the contractors a respectable voice regarding industry standards. They aim to develop the industry by focusing on developing emerging enterprises and providing knowledge to these enterprises through mentoring systems with established enterprises. This organisation integrates with educational systems but only to define jobs in the industry and not to influence the syllabus.

2.2.4.2.5 Summary of boards and institutions

After investigating the strategies and aims of these developing organisations the overall emphasis is found to be on development of the industry but the focus on technology and innovation as part of development is not noticeable. It can therefore be deduced that the South African construction industry has many different organisations and boards dedicated to the development of the industry. However, there is no evidence that these boards and institutions have current plans of incorporating technological innovation and R&D as part of development.

2.2.4.3 Educational structure for innovation and entrepreneurial stimulation

Chapter 9 of the National Development Plan (NDP) of the National Planning Commission (NPC) describes that better education, training and innovation within South Africa are central to the long term development of the country (National Planning Commission, 2011). Technology and science education, especially in higher education, is stated to be the main drivers of innovation in South Africa (National Planning Commission, 2011). Schools are the building blocks for socialisation and learning. Schools lay down the values that permeate society and influence further education, college and higher education significantly (National Planning Commission, 2011). Given the knock-on effect of schooling, it can have a big influence on the society's ability to innovate (National Planning Commission, 2011).

The NDP sates that universities have grown and increased their dominance of being knowledge producers. Universities produced 80% of all scientific research knowledge in 1995 and this has grown to 86% in 2007 (National Planning Commission, 2011). Although the NDP states that universities are the main producers of new knowledge, universities do not have the knowledge production monopoly globally. Science councils, privately funded research institutions, state owned enterprises (SOEs), government departments and the private sector have also become sites of knowledge production (National Planning Commission, 2011). The NDP also states that over the past years little increase was seen in the amount of PhD graduates and researchers in the public sector of South Africa (National Planning Commission, 2011). South Africa is far behind in terms of the number of PhD graduates produced per million citizens. Figure 2.7 shows the annual numbers of PhD graduates, per million citizens, across the world in 2011.

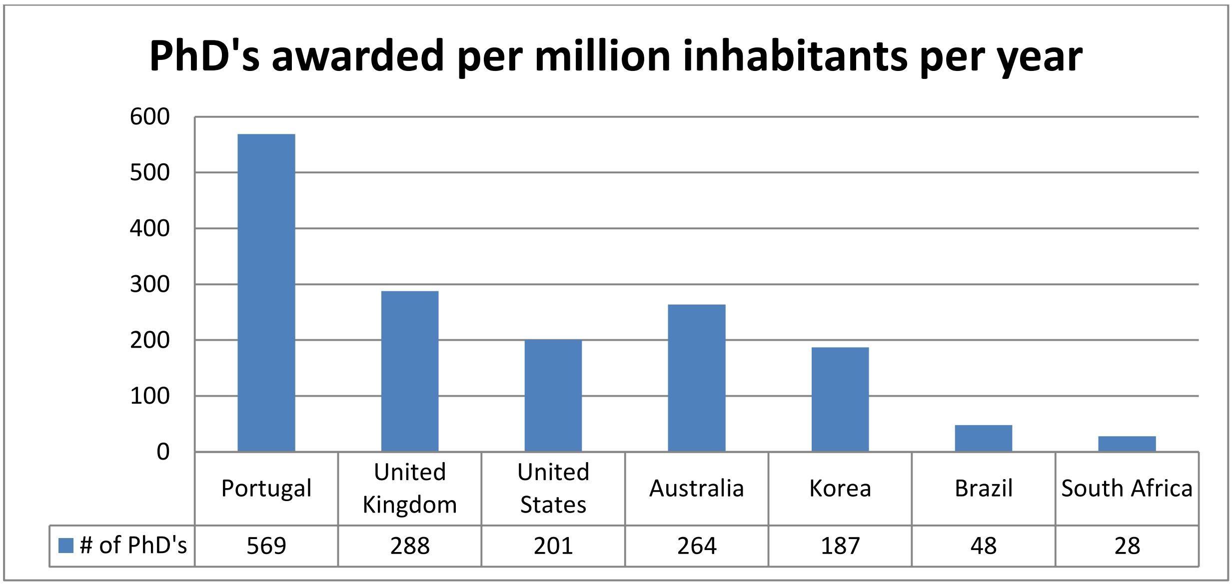

Figure 2.7 - Number of PhD graduates per million citizens per year in countries across the world (National Planning Commission, 2011).

World-class innovation and research will be encouraged if a broad and enabling framework and policy exists. Ideally this should be developed by letting government departments work together (National Planning Commission, 2011).

The challenges that are identified that prohibit full development in terms of educational development and innovation are divided into the different phases of education. These phases are discussed in the following sections.

2.2.4.3.1 Early childhood development

Cognitive development is highly influenced by food and nutrition. In South Africa, children often grow up with a lack of sufficient amounts of nutrition and food. The impact of this phenomenon is evident from the poor schooling outcomes and low skills base of the children in early childhood (National Planning Commission, 2011).

2.2.4.3.2 Schooling

Low quality education in previously disadvantaged areas still persist and is a major drawback in the ability of the education system to provide relief for poverty in these areas (National Planning Commission, 2011). Low standards and easy grade promotions create a large number of failing students in the standardised grade 12 exams (National Planning Commission, 2011). South African grade-6 reading and mathematics students perform much lower than other African countries (National Planning Commission, 2011). Schools that historically served white students are performing close to the international standards of developed countries (National Planning Commission, 2011). Schools that historically served black students perform worse than historically white schools and a grade 5 student in a historically black school performs worse than a grade 3 student in a historically white school (National Planning Commission, 2011). One of the reasons why historical black school students fail is because of weak capacity in the civil structure with regards to teachers, principals, and system level officials (National Planning Commission, 2011).

2.2.4.3.3 Further education, training and skills development

According to the NDP document, the further education training and skills sector has many areas in which it is underperforming. This sector only enrols one third of the amount of learners that are enrolled for higher education (National Planning Commission, 2011). This should ideally be the other way around so that Further Education and Training (FET) colleges and other public colleges enrol the majority of learners (National Planning Commission, 2011). The reason being that there are more individuals who do not qualify for higher education, based on their school education, but can be enrolled into a FET college.

FET colleges have a very low success rate and had a pass rate of 4% in 2009 (National Planning Commission, 2011). Not only is the success rate in terms of qualifying and passing low but the dropout rate is between 15-25% per annum. The FET colleges have weak relationships with industry and workplaces and therefore have a lack of proper and practical training (National Planning Commission, 2011).

2.2.4.3.4 Higher education

According to the academic ranking of world universities in 2008, South African higher education was placed between 27 and 33 along with other countries such as Hong Kong, New Zeeland and Ireland (National Planning Commission, 2011). This is an exceptional rating, but the higher education sector has many underperforming areas and can thus perform better. Problems include the low participation rate and high attrition rates (National Planning Commission, 2011). Also, complaints of the curriculum that does not address society and its needs are experienced. South Africa's higher education system also has an absence of an enabling environment which does not allow individuals to develop to their full potential (National Planning Commission, 2011), the worst of which is a poor knowledge production environment that causes a low level of innovation (National Planning Commission, 2011).

2.2.4.3.5 Summary of educational structure for innovation

In this section it could be seen that the educational structure of innovation in South Africa has many drawbacks. Higher education is the area in which South Africa has a good rating when compared to other countries worldwide and yet the biggest problem is the lack of an enabling environment to develop a higher level of innovation. These drawbacks could explain why there is little technological innovation and R&D in construction. However, this section only investigated the causes and reasons, within the different phases of education, why South Africa is negatively influenced in terms of innovative thinking. Further investigation was therefore done to know where South Africa lies in terms of technological innovation and R&D in a global perspective.

2.2.4.4 South Africa in a global perspective

Data regarding research in Africa has shown that the proportion of research publications has declined over the years. South African is the leader in terms of production of publications, however just as with the ICT statistics, South Africa's lead is being minimised by areas in North Africa (National Planning Commission, 2011). The percentage distribution of publications within countries in Africa is shown in Figure 2.8.

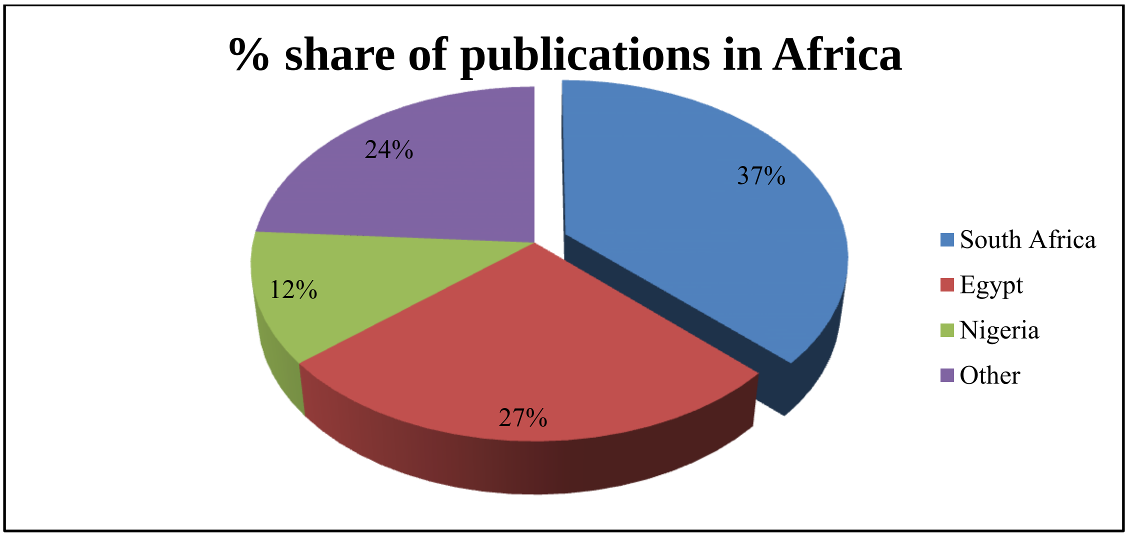

Figure 2.8 - Distribution of research publications in Africa (World Economic Forum, 2012)

According to the global competitive report of the World Economic Forum (2012) economies are divided into three main categories of competitiveness. The categories are 1) factor driven, 2) efficiency driven and 3) innovation driven. Figure 2.9 shows how different pillars are grouped within the categories to define the focus areas of the specific economies. The World Economic Forum (2012) also classified economies in the transition phases between these three categories and an economy could be classified as being between the efficiency driven category and the innovation driven category. South Africa is categorised in the efficiency driven category together with another 32 economies. There are 21 economies categorised between efficiency driven and innovation driven and 35 economies as innovation driven. As economies develop they move from efficiency driven to innovation driven economies. This is, therefore, an indication that South Africa has some way to go before the country's economy is globally competitive. South Africa was rated 50th on its global competitive index in 2000 and is now ranked 52nd for the 2012-2013 term (World Economic Forum, 2012).

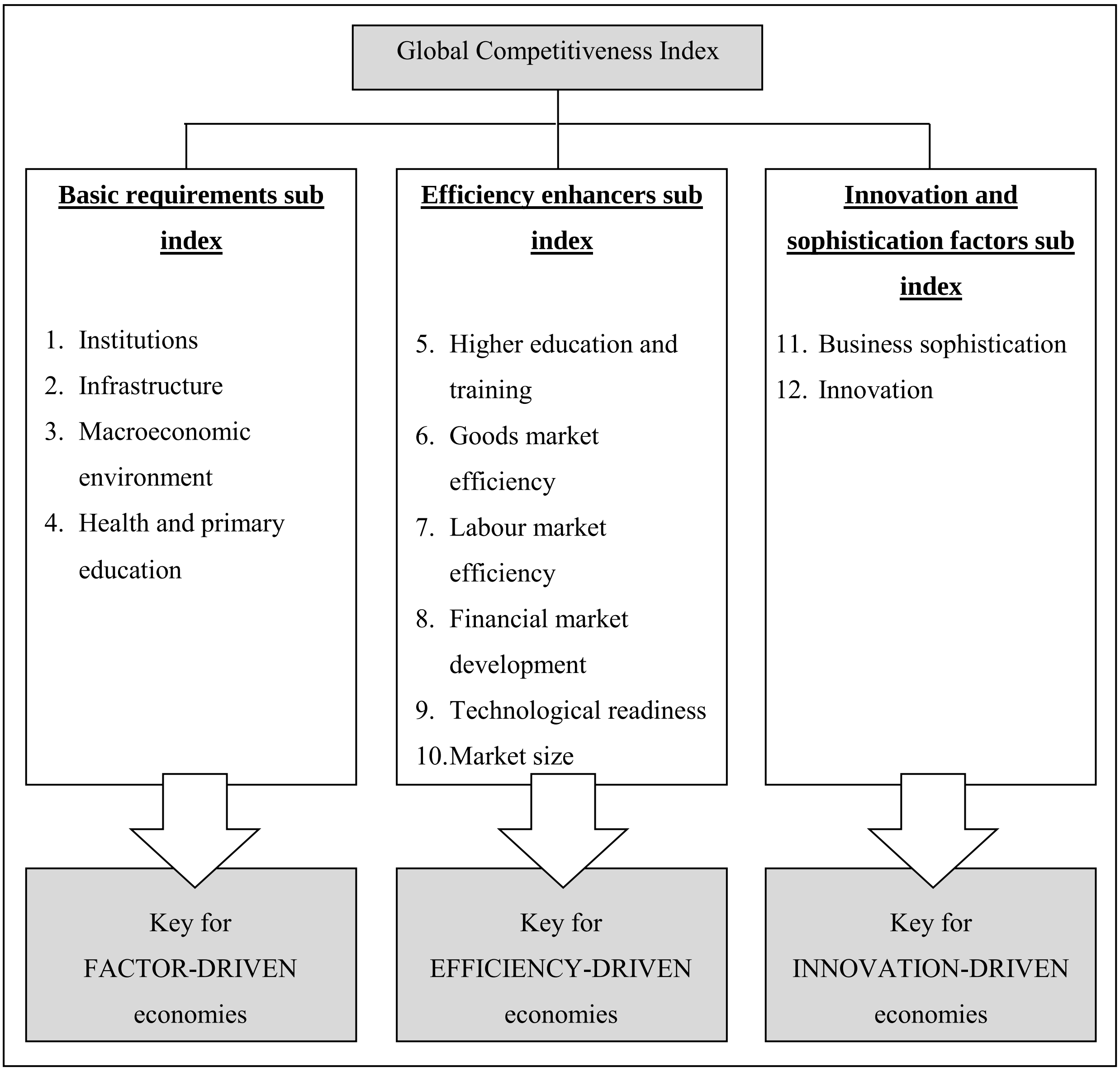

Figure 2.9 - Different pillars grouped in the global competitive categories (World Economic Forum, 2012).

The NDP states that South Africa's innovation and science system is small relative to international standards (National Planning Commission, 2011). The natural sciences is regarded as the fundamental field for global competitiveness and does, however, produce more accredited research outputs than the humanities and medical sciences (National Planning Commission, 2011).

When comparing the expenditure, as a percentage of the GDP, on R&D in South Africa (0.92%) against Norway (1.62%), it is understood why Table 2.3 shows a vast difference in the number of researchers and PhD's delivered per million people living in the country (National Planning Commission, 2011). The realisations of these statistics have caused South Africa to invest more into higher education in the hope that research statistics could improve.

Table 2.3 - The difference in research statistics between Norway and South Africa (National Planning Commission, 2011).

Field/ Discipline/ Category	Norway	South Africa
Full-time researchers	25000	19000
Scientific publications produced	6815	5045
PhD's produced per million people per year	151	28

However, one must not think that substantial investment into higher education will produce better outcomes. This statement is clarified by the NDP which stated that the gap between enrolment and attainment has narrowed, but that investments have not raised the outcomes or graduation rates (National Planning Commission, 2011). This shows that investment in some of the other phases of education is needed so that more graduates can be attained at higher education level.

When comparing South Africa in a global context, the country is not delivering the results it is expected to deliver. The South African economy is in the developing stages but still below other comparable countries. As for research, statistics also do not look good. Despite investment increases in higher education research, the results have not improved. These findings could also contribute to the reason why there is a lack in technological innovation and R&D in the construction industry.

2.2.4.5 Summary of the existence of R&D in construction

To summarise the existence of R&D in construction, it can be stated that the four areas investigated proved that South Africa is not performing up to a competitive standard with its counterparts. After describing innovation and technology, the boards and institutions that are focused on construction industry development, showed no evidence of integrating technological innovation and R&D in their development strategies. The South African education structure for innovation also showed drawbacks that can attribute to the lack of innovation and R&D. When comparing the statistics of R&D and competitiveness of South Africa to the rest of the world, South Africa again showed to fall short of the expected performance. The areas investigated in this section therefore explained why the existence of technological innovation and R&D of South Africa is not on a competitive level.

2.2.5 Innovation within subcontracted companies versus large construction companies

During an interview conducted with one of the division managers at AVENG Grinaker, a question was asked about innovation and R&D in construction technology. The response to the question was that within that business division the subcontractors use new technology, but this is done at their own risk. This answer provided sufficient reason to further investigate if there are different ways of approaching technological innovation in construction when comparing companies that are often subcontracted to established larger construction firms.

An investigation was made into a case study (Eversheim, 2003) of the Hilti Group, a company which is subcontracted on a regular basis by AVENG Grinaker (Passmore, 2012). The Hilti Group offers a range of drilling, dismantling and fastening systems to professional users in the global construction industry (Hilti Corporation, 2011). The company places the customer at the top of the organisational structure to emphasise Hilti's inherent priority of client satisfaction. The client is seen as the main focus of input into improvement (Hilti Corporation, 2011).

The organisation has various business units that are orientated towards their product lines. Corporate Manufacturing is part of the Corporate Functions division which also includes Corporate Sourcing, Corporate Logistics and Corporate Engineering (Hilti Corporation, 2011). It is the responsibility of the different business units across the country to place orders to Corporate Manufacturing for the required products. These orders are based on the requirements of the customer (Hilti Corporation, 2011).

A dedicated Corporate Research and Technology division exists within the Hilti organisation and it is responsible for doing research into innovative solutions that can attend to the specific requirements of the customer (Hilti Corporation, 2011). The division is also responsible for regenerating existing business opportunities as well as identifying and developing new opportunities. Feedback from the customer and the other divisions are incorporated into creating suitable innovations (Hilti Corporation, 2011). This is done to make Hilti a competitor in supplying the most suited power tools for construction professionals (Hilti Corporation, 2011).

In 1992 three of the different business units in Hilti logged similar complaints with regard to the positioning of the tools (Eversheim, 2003). The complaint had gained the status to be further investigated due to the widespread scope of the problem. The new business and technology division was asked to do research into this issue and video analysis was done with regard to worker behaviour on site (Eversheim, 2003). Results proved that, out of the six distinct phases of a task performed with the equipment, the measuring and marking takes the most time with an estimated 28% of the task duration (Eversheim, 2003).

This problem was investigated and various proposals were drafted in a report to the top management at a corporate innovation workshop. The proposals were then evaluated and scrutinized in terms of potential profit and probability of success. The probability of success was based on the technical success probability and the market success probability (Eversheim, 2003). Hilti went on to launch a new product with success and good sales rates (Eversheim, 2003).

In this case the Hilti group is a good example of how a focus on research based innovation and technology was utilized to produce corporate success given a problematic area (Eversheim, 2003).

When it comes to large construction companies, investigation was done into the top four construction companies operating in South Africa (Salami, 2007). Correspondence with some of these top companies and other companies was the basis on which deduction were made. The construction companies that responded included: Aveng Grinaker LTA, Murray and Roberts, Group Five Ltd. and WK Construction.

Correspondence with management of these companies made it clear that very little dedicated research is done in the fields of identifying technologies to help develop new construction methods (Schonrock, 2013; Jackson, 2013; le Roux-Arries, 2013; Phenix, 2013; Egerton, 2013). Egerton (2013) stated that although WK Construction does not have a R&D division, it is something that management have identified as needed from a strategic point of view. Jackson (2013) and le Roux-Arries (2013) representatives of Aveng Grinaker LTA, stated that there is no dedicated R&D division and that new decisions are made by experienced managers when something new is proposed. These new ideas are often proposed at pre-tender stage to an executive board that need to approve the tender.

Phenix (2013), a representative from Group Five Ltd. stated that because their work requires equipment and labour no new methods of construction are investigated and that no dedicated R&D division exists. Schonrock (2013) on the other hand mentioned that Murray and Roberts has a R&D division focusing mainly on concrete with some brickwork and formwork. This R&D division is situated only at the head office and strives to give input into the company so that a competitive advantage is gained (Schonrock, 2013). When asked further Schonrock (2013) stated that the implementation of new proposed methods or technology is decided by the individuals in charge of the project where it is proposed to be implemented (Schonrock, 2013). The risk on whether to try new ideas fall on these project managers and therefore they need to have the final say (Schonrock, 2013).

It can therefore be deduced that there is a difference in approach to innovation and the incorporation of R&D and new technology between large contracting companies and a company that is regularly subcontracted. Although some of the interviewed managers have made mention that R&D is something to be implemented from a strategic point of view, little dedicated technological innovation and R&D exists at the moment.

Hilti, a company regularly subcontracted, showed similarities in the approach to technological innovation and R&D to that of manufacturing companies. Both Hilti and manufacturing companies place great emphasis on the importance of the customers' input during research on improvements. In both cases the customer provides input, in terms of demands, requirements and the product, with the aim to refine technological research. The larger construction companies showed evidence that the project managers have to decide on new technology. With little dedicated R&D divisions these new technologies will have to be identified by the individuals themselves and decisions have to be made without reports from a dedicated R&D division.

The difference in approach of the larger construction companies and the subcontracting -, or manufacturing companies can not necessarily be attributed to the size or type of company. The approaches could be attributed to the business strategies of the company. An investigation on business strategy and decision making in construction will therefore be discussed in Chapter 7.

From this section one can conclude that there are different approaches to implementing technological innovation and R&D. This section also showed that these different approaches created differences in the extent to which technological innovation and R&D is being implemented.

2.2.6 Summary of technological innovation and development in construction

In summary, section 2.2 provided an explanation of why companies change, by describing that the development of technology and customer requirements are included in the list of drivers for change. Technology and innovation were defined so that it is clear that inventions are not the same as innovations and that technology is an ever evolving concept with different descriptive prefixes. The discussion on the importance of technology showed that it is one of the most powerful tools for knowledge management and that technology has proved to deliver better project performance. The discussion on the existence of R&D produced evidence that South Africa is not performing on a competitive level when compared to its counterparts. Also, the boards and institutions, focused on construction development, show no signs of promoting technological innovation and R&D as part of development. Furthermore it was seen in this section that the education structure has drawbacks that could be a cause for the lack in innovation and R&D. This section also covered the existence of R&D in construction and discussed the difference in approach to innovation of large contractors and a regularly subcontracted company.

2.3 Conclusion

In the first section of this chapter a summarised explanation of the construction industry was given. This included stating the size of the industry together with a number of statistics about the amount of resources the industry uses. Mention was also made of the benefits and importance of the construction industry to a country and its economy. Following these discussions, investigation was conducted with regards to the different role-players directly involved with construction and its projects. These role-players were described and their roles and responsibilities were discussed to give the reader a sense of who is responsible for which parts of the construction project. The phases of a construction project were given and the operations phase was identified as the phase that uses the most resources during a construction project. For this reason focus was placed on this phase of a construction project and on contractors, who are mainly responsible for the success of this phase. It was also found that the different divisions of civil engineering execute the operations phase differently. The different civil engineering divisions were therefore investigated. During investigation of the civil construction industry it was found that different references define the divisions of civil engineering differently. They also group the fields of work differently into these divisions. A specific grouping of divisions was therefore chosen in this section and it was based on the fact that interviews needed to be conducted with managers, each representing an expert in one of these divisions.

Section 2.2 of this chapter gave insight into the current state of technological innovation and R&D in construction and in South Africa. The first part of the investigation was into the reasons why companies change. It was found that there are various drivers of change, both internally and externally. These factors concluded that technological change and user demands are some of the important reasons why companies are forced to change. It was also seen that continual improvements had the effect that the users' demands grew due to the fact that they became accustomed to high performance and delivery. Technology and innovation were defined and it was seen that both of these concepts are two of the most important tools for development and knowledge management. It was also made clear that South Africa as well as the boards and institutions, which are focused on development, are not performing as expected when compared to global counterparts in terms of R&D and innovation in technology. The education structure for innovation in South Africa has drawbacks, identified in the chapter, that could explain why there is a lack in technological innovation and R&D. It also became clear that there are different approaches in different businesses towards R&D and technological innovation, and that most of the larger construction companies do not have dedicated R&D divisions looking into innovation and technology.

CHAPTER 3

Identification of areas of concern in the construction industry

The next step of this research, as outlined in section 1.5, is to identify areas of concern within the construction industry. An area of concern can be defined is follows:

> *Area of concern – A worry, interest or anxiety within a company or industry. It is problematic or limiting and causes the need for resolution in order to improve product or service delivery.*

This chapter will, therefore, identify areas of concern in construction which will serve as an interim step towards improving the current state of construction in South Africa as explained in Chapter 2. This chapter will also provide information for two of the research questions stated in section 1.3.2. These two questions are:

1. Are there any generic areas of concern in the different divisions of civil engineering?
2. What is the most influential area of concern in the South African construction industry?

The influence of an area of concern had to be determined in order to answer the second question mentioned above. This process of determining the influence of areas of concern will be explained in section 3.2 and includes how the area of concern influences cost, time, risk and quality of construction projects. The area of concern with the biggest impact on these areas of a project will be regarded as the most influential area of concern. Once the most influential area of concern is identified it will be used as a relevant example to establish and work through a process that can assist technology investments in construction.

There are various ways in which improvement can be made, and continual process improvement (CPI) is a term described by Rummler and Brache (1995) as the way in which businesses can improve. 'Kaizen' is a Japanese term for this gradual improvement process that incorporates all elements of the business, including employees from top management to the labourers. Furthermore Rummler and Brache (1995) as well as Coleman and Endsley (1999) suggest that there are phases in the improvement process. Both these publications refer to the first phase of improvement as the analysis phase. This initial phase outlines the identification of problematic areas as one of the main tasks. Therefore, in order to develop and improve, a company has to first try and eliminate areas of concern that are preventing systems to be optimal. Consequently, this chapter will describe the methods used to identify the main areas of concern in civil engineering construction.

As mentioned in the literature study in Chapter 2 this study focuses on the operations phase of construction, in light of the amount of resources used in this phase. For this reason we will identify the areas of concern within the operations phase of a construction project. To identify the main concerns in construction is not easily done, due to the differences in experiences of construction industries across the world. In Chapter 2 it was evident that South Africa had many areas that can be improved and for this reason the major areas of concern within a narrowed South African context will be investigated.

These major areas of concern were identified using a two-phase process. The first phase of the process, initial area of concern identification, was executed in three steps as shown in Figure 3.1. The second phase of the process involved the selection of the most influential area of concern. This final phase of the identification process was performed in a further two steps. The two phases of this identification process will now be discussed.

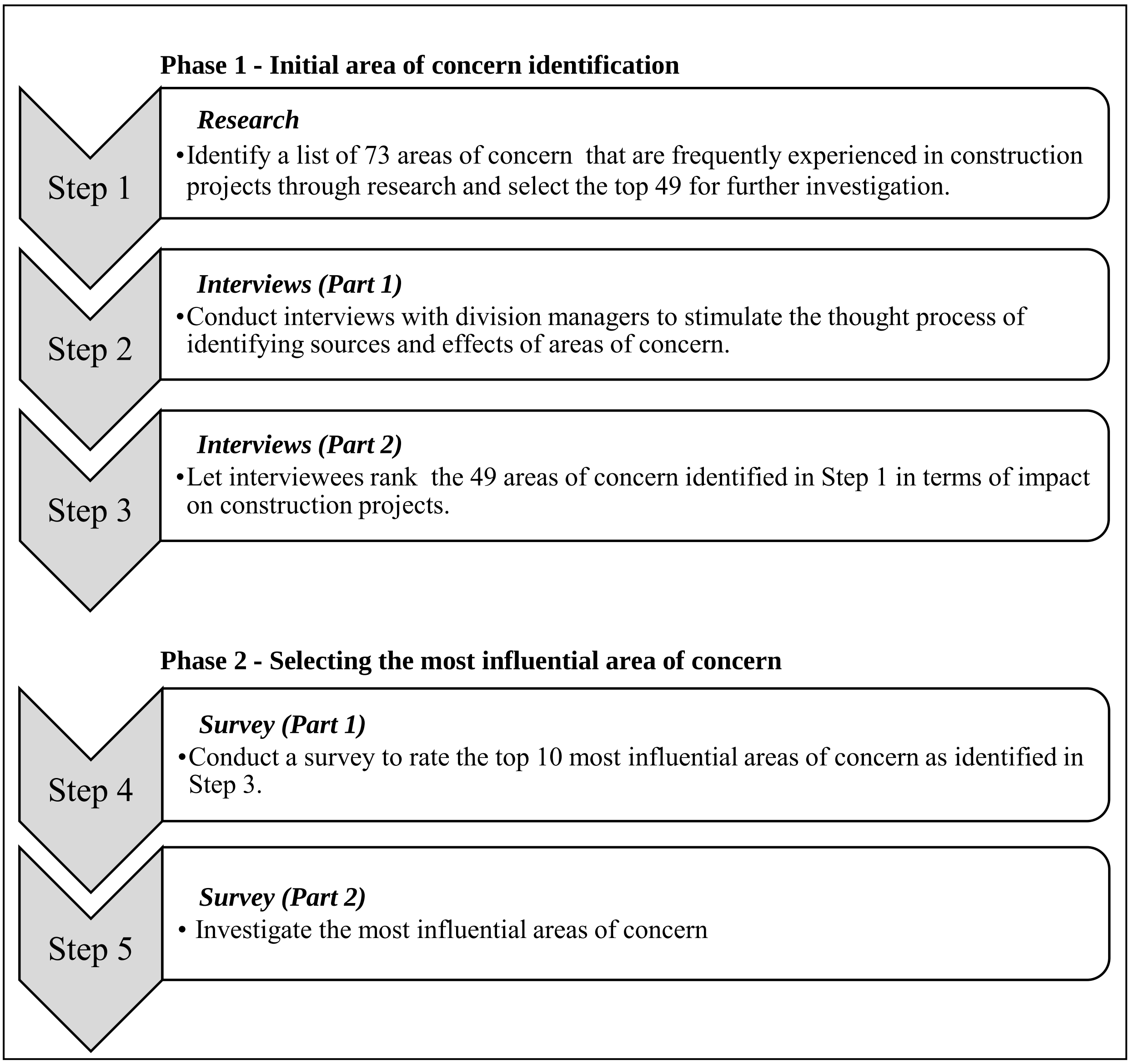

Figure 3.1 - Process of identifying areas of concern in the construction industry

3.1 Initial area of concern identification

As seen in Figure 3.1, the initial area of concern identification is the first phase of the process and the first step was to do research. This research involved identifying areas of concern in construction. In a publication of Assaf and Al-Hejji (2006) 73 areas of concern were identified and compiled into a list. This list of areas of concern was constructed to identify areas that influence the operations phase of a construction project. This list was constructed based on questionnaires sent out in Saudi Arabia and the areas of concern were ranked in order of highest frequency of identification. This meant that the highest ranked area of concern was identified by most of the survey respondents and had a high frequency of identification. The rankings of this list were calculated from the inputs of respondents from Saudi Arabia only and could not be used in a South African context. For this reason the areas of concern that had the highest frequency of identification were used for further investigation. This investigation will be discussed in a step 3 of the process. The top 49 areas of concern, based on the results of Assaf and Al-Hejji (2006), were therefore taken without ranking and placed in a sample list. The order of the areas of concern was determined not by the rankings from their findings but rather categorised based on the different sources of the areas of concern. The sources were identified by Assaf and Al-Hejji (2006) and included the contractor, consultant, materials, equipment, labour and external factors. The sample list can be seen in Appendix A.

The second step in the process involved interviews with South African contractors so that the data of the research could be validated and put into a South African context. The different individuals were strategically selected to each represent an area of specialisation in the civil construction industry as identified in section 2.1.4. These individuals could, therefore, identify the areas of concern experienced by the different civil divisions. The selection of managers in these divisions was important, because the answers on the questions would then include the mind-set of the current management processes in place. The selected interviewees thus gave a true representation of how the areas of concern are treated given existing business procedures focused on CPI.

The interviews were constructed in two parts as seen in Figure 3.1. The first part of the interviews comprised of a list of questions that encouraged the chosen individuals to think critically about their specialist division. These questions were aimed at identifying areas of concern in the respective specialised divisions. The individuals were also asked to identify the effect of the area of concern on cost, time and quality of projects. When different concerns were identified, time was spent to identify where the concern originated from.

Many of the individuals identified rework on structures as an area of concern in their specialised division. Rework on structures will be used as an example in order to explain how the thought process was stimulated. After Farber (2012), one of the interviewees, identified that rework was an area of concern in his division, a range of questions was asked in order to identify where the rework concern originates from. The lack of correct information and specifications was for instance proposed as the origin of the rework concern (Farber, 2012). After the origin of the concern (lack of information and specifications) was identified by Farber (2012), the effects caused by this source were assessed to see if the knock-on-effects lead to rework. It was discussed that, although the labourer could have years of experience doing a specific task, incorrect information was likely to result in a section of work that was incorrectly built. This would cause that section to be demolished and that rework was needed to correct that mistake (Farber, 2012). In this case "lack of correct information" was found to be a valid origin of the rework concern.

This questioning, identification and assessment procedure ensured that the individual under question could identify what the wider impact and knock-on effects of a specific area of concern on the project could be. It was also seen that while critically assessing these areas of concern, some individuals under question came to realisations that could possibly solve the concerns under question (Passmore, 2012). The value of searching for the source of a problem was realised by some of the interviewees (Jackson, 2013; Bothma, 2012; Farber, 2012). Rummler and Brache (1995) also value the mechanism of identifying the source of a problem rather than trying to solve the effects it creates. This realisation supports why the theme of this chapter can play an integral role in the improvement of construction.

The second part of the interviews, and the third step of the process, was conducted by giving the interviewed individuals the list of 49 areas of concerns identified in Step 1. Given this sample list of areas of concern, the interviewees were asked to rate the areas of concern in terms of the impact it has on the operations phase of a construction project. A model was defined by which the areas of concern needed to be rated. This model consisted of four main elements that needed to be taken into account when determining the magnitude of the impact of an area of concern. These elements of the model were cost, quality, time and risk of construction projects.

The individuals were asked to rate the list of construction areas of concern on a scale of zero to ten. They had to take the four factors of the model into account as well as the frequency of occurrence within their division. Zero indicated that the area of concern does not have a big influence on a project's time, cost, quality and risk in combination. Ten was an indication that the area of concern caused a large negative impact on the elements of the model.

During the interview process discussions were recorded with the approval of the interviewee. The recorded interviews provided good data because it captured the initial reactions of the individuals. This provided an indication of the way in which the areas of concern are perceived by the company at that given time. The recorded data was therefore also the basis for further correspondence with the interviewees after the recordings had been analysed.

The ratings given (R) to the areas of concern (O) by the interviewees (M) were transcribed into a matrix and processed in a spreadsheet as seen in Appendix B. An average rating (R_A) was then calculated for each of the specific areas of concern by taking all the interviewees' ratings into account. The weight of each individual's rating was based on the experience and position they currently held within the company. This resulted that the weights were taken as equal. The division managers ranked the influence of a concern by assessing its impact on a construction project. The most influential area of concern is therefore the area of concern with the biggest impact on construction projects.

Each area of concern is represented by the symbol O_j and has a subscript j that ranges from 1 to 49 representing the different areas of concern listed in the second column of the table in Appendix A. The different interviewees are represented by the symbol M_i and has a subscript i ranging from 1-4 representing the four different managers who were used as interviewees. A rating R is a function of a specific interviewee and an area of concern, thus $R(M_i,O_j)$.

An average rating $R_A (O_j)$ is a function of an area of concern and is calculated using Equation 3.1.

$$R_A(O_j) = \sum_{i=1}^{4} R(M_i, O_j) \Big/ 4 \quad \text{.......} 3.1$$

One of the areas of concern in the list in Appendix A was low labour productivity. This area of concern, symbolised by (O_{36}), will be used as an example to explain the calculations that will follow. The first interviewee was the structural manager (M_1) and he rated the area of concern (O_{36}) to have an influence with a magnitude of 6 out of 10. This means that the $R(M_1, O_{36})$ was equal to 6. The same was done by the other managers and yielded an 8 for both the water- and transport managers and a 5 for the geotechnical manager. The average rating (R_A) was calculated by adding all the ratings of the different interviewees together and dividing the total by the number of interviewees. Equation 3.2 is how the average rating of labour productivity $R_A(O_{36})$ was calculated.

$$R_A(O_{36}) = \sum_{i=1}^{4} R(M_i, O_{36}) \Big/ 4 \quad \text{.......} 3.2$$

$$= [R(M_1, O_{36}) + R(M_2, O_{36}) + R(M_3, O_{36}) + R(M_4, O_{36})]/4$$

$$= [6 + 8 + 8 + 5]/4$$

$$= 6.75$$

The R_A of all 49 areas of concern was calculated and the areas of concern were ranked from highest R_A value to the lowest R_A value. This ranked list of areas of concern can be seen in Appendix B.

This list showcases the impact of these areas of concern on a construction project as perceived by some South African contractors. In order to improve the results and get a better South African perspective a larger audience was asked to rate these areas of concern and this is discussed in the next section that investigates the second phase of the identification process.

3.2 Selecting the most influential area of concern

It was decided to select the ten areas of concern with the highest R_A ranking from the previous step for further investigations. The reason for this reduction in the number of areas of concern investigated, was to increase the quality of the feedback from surveys and also to narrow the scope of the research so that detailed investigations can take place on a selected amount of areas of concern. A shortened list of the ranked list of areas of concern can be seen in Table 3.1.

Table 3.1 - Ranked areas of concern as calculated based on interviews with division managers.

Rank	Concern (O)	Description of area of concern	Source	Rating by manager (R)				Ave. Rating (R_A)	Std. Deviation
				Slip form (M_1)	Dam wall (M_2)	Bridges (M_3)	Retaining (M_4)		
1	15	Delay in approving major changes in the scope of work by consultant	Consultant	4	5	7	10	6.5	2.64
2	18	Late in reviewing and approving design documents by consultant	Consultant	4	5	6	9	6	2.16
3	36	Low productivity level of labourers	Labourers	4	8	8	4	6	2.30
4	7	Ineffective planning and scheduling of project by contractor	Contractor	2	5	5	10	5.5	3.31
5	34	Unqualified workforce	Labourers	2	7	8	5	5.5	2.64
6	9	Delays in sub-contractors work	Contractor	4	7	5	5	5.25	1.25
7	20	Inadequate experience of consultant	Consultant	2	5	6	8	5.25	2.5
8	28	Equipment breakdowns	Equipment	4	4	5	8	5.25	1.89
9	45	Accidents during construction	External	4	6	5	5	5	0.81

As stated in the previous paragraph it was decided to select only the top ten areas of concern for further investigations. However the areas of concern that were ranked 9, 10, 11, and 12 in Appendix B all had the same R_A. The only separation between these areas of concern was the standard deviation of the different ratings given by the managers. If the standard deviation is smaller it means that the managers agree more on the magnitude of the influence on a construction project. It was therefore decided to make use of the smaller standard deviation, when faced with a scenario like this. Only the area of concern that was ranked 9th had a smaller standard deviation than the areas of concern ranked 10th,11th and 12th. It was therefore decided to rather investigate the top nine areas of concern than to investigate the top 12 areas of concern. These nine areas of concern can be seen summarised in Table 3.1.

The process of selecting the most influential area of concern was done using a two step selection process. This selection process was conducted by ranking the top nine areas of concern in terms of the impact they had on various areas of a construction project. The second step was to investigate specific aspects of the areas of concern with the biggest average impact on construction projects i.e. most influential areas of concern. The nine areas of concern that had been ranked by division managers had been used in a survey amongst delegates at the 2012 Construction Management Programme (CMP) (Construction Management Programme, 2013). The questionnaire used for this survey can be seen in Appendix C and the data of the first hand-out can be seen in Appendix D. These 38 delegates consisted of directors, managers and site agents with experience in the South African construction industry. The construction experience of the delegates ranged from 6 to 30 years, with an average of 16 years of experience in construction. The delegates were selected and sent by companies to attend this programme to gain valuable insight into key concepts of management in the development of infrastructure.

These 38 delegates rated the nine areas of concern (O_i), and used a scale of 0-10 to quantify the degree of impact on areas of a construction project where zero indicated a minor impact and ten indicated a major impact. The areas of concern have a subscript i that indicates the number of the areas of concern as listed in the first column of Table 3.2. The impact on a construction project was, however, separated into different impact areas and an individual could value the impact of the area of concern on project time (T_d), project cost (C_d), quality of work (Q_d) and project risk (R_d). These impact areas have a subscript *d* that indicates the different delegates, ranging from 1-38, that were used in the survey. The impacted areas, T, C, Q and R, together form the impact model. An example of one of the delegates' rating sheet can be seen in Table 3.2. This sheet shows how this specific delegate rated the impact of the nine listed areas of concern on the elements of the impact model.

A scrutiny of Table 3.2, which is an example of one of the delegates' input, shows that this delegate (d) rated 'Low productivity level of labourers' (O_3) to have an impact of 8 out of 10 on the time of a project (T). Each delegate rated the nine areas of concern in this way. The values of the 38 rating sheets were averaged to get an average value of the impact each area of concern had on the different elements of the impact model. The average value of an area of concern on time is symbolised by I_T. The average impact on cost is symbolised by I_C and those of risk and quality are I_R and I_Q respectively. These average values are calculated by using equations 3.3, 3.4, 3.5 and 3.6.

Table 3.2 - A delegate's rating sheet of impacts of areas of concern on different elements of the impact model.

Area of concern (O)	Description of area of concern	Impact Areas			
		Time (T)	Cost (C)	Quality (Q)	Risk (R)
1	Delay in approving major changes in the scope of work by consultant	1	3	2	1
2	Late in reviewing and approving design documents by consultant	1	2	2	2
3	Low productivity level of labourers	8	10	10	10
4	Ineffective planning and scheduling of project by contractor	7	7	7	7
5	Unqualified workforce	7	7	8	8
6	Delays in sub-contractors work	6	6	7	8
7	Inadequate experience of consultant	1	1	1	1
8	Equipment breakdowns	6	9	9	9
9	Accident during construction	8	8	8	10

$$I_T(O_i) = \sum_{d=1}^{38} T_d(O_i) \Big/ 38 \quad \text{.......... 3.3}$$

$$I_C(O_i) = \sum_{d=1}^{38} C_d(O_i) \Big/ 38 \quad \text{.......... 3.4}$$

$$I_Q(O_i) = \sum_{d=1}^{38} Q_d(O_i) \Big/ 38 \quad \text{.......... 3.5}$$

$$I_R(O_i) = \sum_{d=1}^{38} R_d(O_i) \Big/ 38 \quad \text{.......... 3.6}$$

Table 3.3 shows the result of the average for the different impact areas, I_T, I_C, I_Q and I_R, for a given area of concern. It was realised that, depending on the strategy of the company and the specific project, the importance of cost, time, quality and risk can differ. The delegates of the survey were from different fields and different companies that could possibly place a different value to the importance of these impact areas. For this reason it would have been challenging to create a weight for each of these areas that incorporated the value of importance of all the delegates. Therefore an assumption was made to equal the importance of these impact areas in the calculations and thus assign a weight of one to all of these impact areas.

The impact areas were all ranked with a range of zero to ten and were, therefore, rated relative to each other. The impact areas could therefore have a relative importance already incorporated. This supported the assumption to equal the weights of the impact areas when calculating the average impact on a project.

The average values of impact, I_T, I_C, I_Q and I_R, were used to determine the average impact the area of concern has on a project. This average impact on a project is symbolised by I_{AVE}. These average values are a function of an area of concern and is calculated using Equation 3.7.

$$I_{AVE}(O_i) = \frac{I_T(O_i) + I_C(O_i) + I_Q(O_i) + I_R(O_i)}{4} \quad \ldots\ldots 3.7$$

The results of the average impacts of the different areas of concern on the project can be seen in the last column of Table 3.3. As an example, the calculation of the I_{AVE} for 'Low productivity level of labourers' $I_{AVE}(O_3)$ is calculated in Equation 3.8.

$$I_{AVE}(O_3) = \frac{I_T(O_3) + I_C(O_3) + I_Q(O_3) + I_R(O_3)}{4} \quad \ldots\ldots 3.8$$

$$= \frac{7.69 + 7.72 + 8.19 + 7.92}{4}$$

$$= 7.88$$

Given the average impact value of a specific area of concern, the areas of concern were ranked from the highest average impact to the lowest average impact. These results showed that the CMP delegates of 2012 rated low productivity and qualification of labourers, respectively, to be the number one and number two areas of concern in the South African construction industry.

From Table 3.3 it can be deduced that the most influential areas of concern, in terms of both time (I_T = 8.50) and cost (I_C = 8.31) impact, are regarded to be the 'approval of major scope changes by the consultant'. This can be expected because the tender documents that contractors submit, are greatly optimised for a specific scope of works and any change in scope could have a major influence on the cost and time estimates.

Table 3.3 - Calculated averages of the impacts that areas of concern have on the impact areas.

Area of concern (O)	Description of area of concern	Impact Area (I)				
		Time (I_T)	Cost (I_C)	Quality (I_Q)	Risk (I_R)	Average (I_{AVE})
3	Low productivity level of labourers	7.69	7.72	**8.19**	7.92	7.88
5	Unqualified workforce	7.97	7.94	6.69	**7.94**	7.64
7	Inadequate experience of consultant	7.97	8.03	6.17	7.75	7.48
4	Ineffective planning and scheduling of project by contractor	7.89	7.92	6.67	6.89	7.34
1	Delay in approving major changes in the scope of work by consultant	**8.50**	**8.31**	5.11	6.94	7.22
6	Delays in sub-contractors work	7.69	6.97	6.19	7.42	7.07
2	Late in reviewing and approving design documents by consultant	8.19	7.92	4.81	7.03	6.99
8	Equipment breakdowns	6.31	6.67	4.64	6.22	5.96
9	Accident during construction	6.39	5.86	3.89	6.75	5.72

Jerling (2009) stated that the identification and managing of client-generated risks can reduce project time, cost and other operating margins. In this case '*client*' can refer to the owner, financers or the consultant representing the client in the project. Jerling (2009) also stated that mitigating risks identified at bidding stage, such as possible changes in scope, proved to be the best method to reduce cost and time overruns. These two observations of Jerling support the information established from the survey when comparing how the managers rated the impacts of major changes by the consultant on time and costs.

Labour related areas seem to have the most significant impact on the other two influence areas namely quality ($I_Q = 8.19$) and risk ($I_R = 7.94$). This shows that the CMP delegates see the lack of managing and educating the labour workforce as a major risk that is very influential in terms of quality of construction.

The aforementioned statement is supported by the publication of the CIDB in January 2011 (CIDB, 2011). This document focused on the quality of construction and the relating factors that influence quality. A survey was conducted and the different stakeholders that participated in the survey ranked the factors according to their magnitude of influence. Construction related factors included skills shortages, insufficient workforce training, lack of management commitment and a lack of strict quality and productivity control of workforce (CIDB, 2011). Table 3.4 shows the results obtained by the CIDB in their research. From Table 3.4 it can be seen that an underlying need for better management of resources, barriers 1 and 4, and lack of knowledge, barriers 2, 5 and 7, are prevalent as factors influencing quality.

Table 3.4 - Stakeholder perceptions of Barriers to Construction Quality (CIDB, 2011).

Barrier #	Interventions	Clients	Designers	Project Managers	Contractors		Average	Rank
					Grade 2-4	Grade 5-9		
	Scale: 1 = minor; 3 = average; 5 = major influence							
1	Poor site management	4.4	4.6	4.3	4.7	4	4.4	1
2	Lack of contractor quality expertise	4.6	4.6	4.2	-	4.2	4.4	2
3	Corruption	3.7	4.1	4.5	4.9	4.2	4.3	3
4	Inadequate resourcing by contractors	4.	4.1	4.3	-	4.1	4.1	4
5	Lack of understanding of quality	4	4.4	3.8	4.6	3.7	4.1	5
6	Level of subcontracting	4	3.9	4.2	4.6	3.7	4.1	6
7	Inadequate information	3.6	4	4.3	-	3.7	4.1	7
8	Detail	3.8	4.4	4.3	-	3.7	4.1	8
9	Focus on cost by contractors	4.3	4.1	3.8	3.8	4.1	4.0	9
10	Poor constructability	3.8	4.2	4.2	-	3.8	4.0	10

Education or experience of the workforce is considered to be the second most influential area of concern according to the experienced construction managers of the CMP 2012. Identified as areas of concern at a productivity conference in 1980, education and experience seemed to be significant challenges facing the South African construction industry (van der Merwe, 1980). The prevalence of these problems both then and now suggests that they are enduring challenges and could take time to improve.

The final step of the identification process was to investigate the most influential areas of concern form the list in Table 3.3. This was done by conducting a second survey with the same CMP delegates and only including the top three areas of concern. The reason why only three areas of concern were used for the second survey was to increase the quality of the feedback in the surveys because the second hand-out was a time consuming exercise. If more areas of concern were to be investigated on that level the survey would have taken a long time to complete and possibly influenced the results of the last areas of concern. In selecting only three areas of concern the scope of the research was narrowed so that detailed investigations could take place on a selected amount of areas of concern.

From the results of the second hand-out, it was found that inadequate experience of the consultant could not be influenced by the contractor. This area of concern was therefore not investigated further. Most of the feedback showed that contractors had managed to mitigate the effect of the unqualified labourers with training programmes on and off site. Investigation into the results of the top rated area of concern namely, low productivity of labourers, showed that many companies have tried to address this aspect but have not succeeded. They have tried to manage the problem but none indicated that they implemented technology which they used to address this concern. The first reason why low labour productivity was selected as the area of concern that will be investigated is because of the technological focus of this study and the fact that technology has not been used to address this area of concern. The second and most important reason why low labour productivity was selected was because it was rated to be the most influential area of concern in South African construction projects.

3.3 The magnitude of the most influential area of concern

3.3.1 Overview

As seen in Table 3.2 in section 3.2, the area of concern with the biggest impact on construction projects is the low productivity of labourers during construction. This area of concern was therefore regarded as the most influential area of concern. This area was ranked as the most influential issue based on the impact on time, cost, quality and risk of a construction project. Although the participants are generally highly experienced and the possibility of correct data is high, the potential influence of this concern needed to be verified to gain more validity. For this reason, the time and costs allocated to labour in a project were assessed and established as seen in the following section.

3.3.2 Labour time and cost allowable in construction projects

Dozzi and AbouRizk (1993) stated that the human resource is extremely important to construction and is more important in this industry than any other industry. According to Hendrickson and Au (2008) improvement of labour productivity should be a major and continued concern for project managers and construction companies. The cost and time this resource uses on a construction project was thus investigated in this study.

Hendrickson and Au (2008) stated that management can influence the number of labour hours needed or used more easily than other aspects, such as materials and capital expenditure, to save time on projects. This shows that labour time on a project has a higher potential to be altered or improved in order to save time on a construction project. In a magazine published by the British Broadcasting Corporation, an article was written to showcase the time effectiveness and productivity of work on British nuclear power plant construction sites (Dozzi & AbouRizk, 1993). It is mentioned in this article that during that time there were no plants that were built on time. Some of the projects overshot their expected completion date by two and a half years (Dozzi & AbouRizk, 1993). Statements were made in this publication that productivity levels were unbelievably low and that workers only performed between 1h45min to 45min of work during an 8 hour work day on some of these British construction sites (Dozzi & AbouRizk, 1993).

According to Hendrickson and Au (2008), labour costs constitute a significant part of the total construction cost of a project. However, in South Africa, documents such as the South African National Standards (SANS) 1914-5 and Guidelines for the Implementation of Labour Intensive Projects under the Expanded Public Works Programme (EPWP), compel companies to adapt towards a labour intensive way of executing projects (CIDB, 2005) (Standards South Africa, 2002). A labour intensive approach is defined by the optimal use of labour as the predominant resource for the development of infrastructure. Labour needs to be utilised whilst ensuring cost-effectiveness and delivering quality workmanship (CIDB, 2005). According to (Bental, et al., 2003) the total cost of labour on a labour intensive project should be high and should range between 25%-60% of the total project costs. Optimising the productivity of labourers in South Africa is therefore of paramount importance.

From the above statements it was found that the time of labour and cost of labour are two aspects worth investigating and labour productivity continues to be one of the biggest concerns to South African construction managers. It was also found that although the magnitude of the concern regarding labour time and cost is so significant, they remain the elements that are most susceptible to improvement by management.

3.4 Conclusion

After the interviews had been conducted with specific managers in the different divisions of civil engineering construction, a shorter list of generic areas of concern had been identified. The areas of concern identified by the interviewees were seen as areas of concern that are present, even with the implementation of current CPI and business – and management strategies. After further surveys were issued to delegates at the CMP of 2012, a more precise indication of the areas of concern in South African construction was achieved. The final data from this survey was used to do calculations and perform ranking procedures to identify the most influential area of concern, as rated by the construction managers of the annual CMP programme of 2012. It was seen that the main concern is workforce and labour related.

After the CMP delegates had identified the most influential area of concern, investigation was done to validate whether the identified area of concern is indeed a concern that can have a major impact on construction projects. The magnitude of the concern of low productivity of labourers was, therefore, investigated and it was found that it is indeed a concern that should receive the necessary attention. Labour costs and time proved to be a major concern to most construction managers, but that it is a problem that is susceptible to change if good management procedures are used.

It was therefore seen to be of value to investigate the possibility to address labour productivity concerns on a construction site. The relevance of the above mentioned investigation is further supported by the fact that labour productivity and workforce qualification were ranked as the top areas of concern and because a large percentage of the time and cost of a project is used for labour related tasks. Labour productivity was therefore also used as an example of an area of concern in the process that could assist technology investment decisions.

CHAPTER 4

Labour productivity in construction

In the previous chapter the impact of key areas of concern within the construction industry in South Africa were determined, indicating that labour productivity is the most influential area of concern. This chapter will therefore further investigate labour productivity in construction so that the sources of the concern can be understood and factors influencing labour productivity are outlined. This investigation will then be used in the next chapter to identify where improvements can be made with regards to improving or eliminating the concern of low labour productivity.

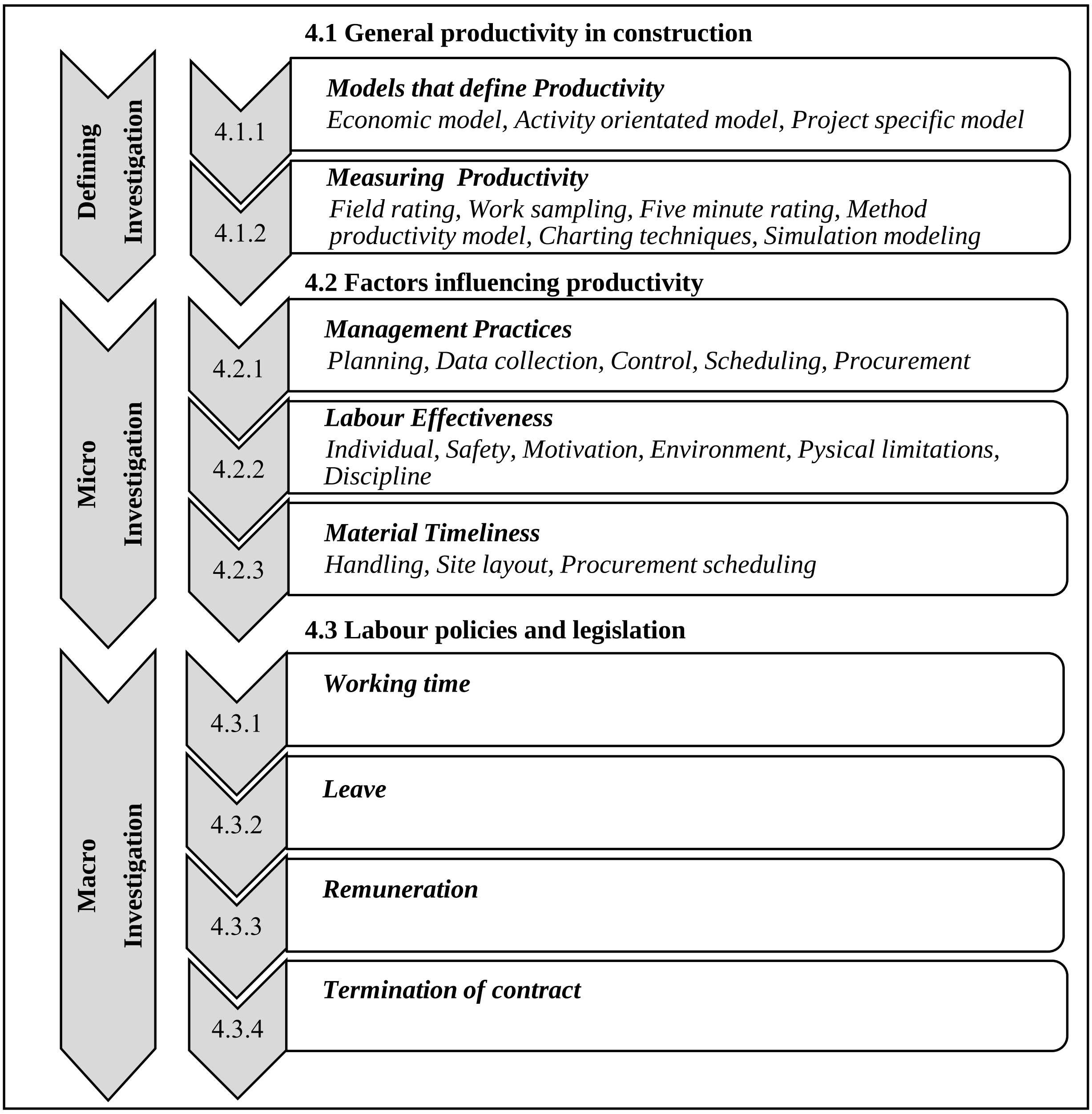

Figure 4.1 - Layout of the investigation of labour productivity in construction

Dozzi and AbouRizk (1993) wrote a textbook on construction productivity and this book was used as the main reference of many sections in this chapter. Their work is verified and supplemented by other authors where applicable.

Dozzi and AbouRizk (1993) stated that once productivity is defined there are two overshadowing areas of productivity investigation and these are the macro and micro environments of productivity in labour. The macro environment involves the contracting methods, labour legislation and labour organisation. Within the micro environment, management and operation of the project on the job site, are covered.

The investigation of labour productivity in this chapter will be done by looking at three areas, namely the defining -, micro- and macro areas of investigation. The defining investigation looks at productivity in general construction terms and makes reference to the different models that define productivity. The micro investigation focuses on the factors influencing productivity in construction. The macro investigation focuses on labour legislation and performance policies. Figure 4.1 on the previous page shows how these three areas of investigation make up the body of this chapter and how the different sections are incorporated into the context of this investigation.

4.1 General productivity in construction

If general productivity in construction is to be investigated, it is important to define what is meant by the term productivity. The term productivity can have different contexts and thus differing associated definitions. It is also necessary to distinguish between a productivity measurement and a work study. Both these terms form an integral part of the initial notion of productivity and it is consequently important to differentiate between them.

Productivity measurement is done by the calculation of equations and expressing different units in terms of each other. Dozzi and AbouRizk (1993) suggest that productivity comes down to an expression of input versus output. These relationships and units differ according to the purpose of the calculation. Different from productivity measurement, a work study is defined when a specific system of works is systematically investigated in order to determine the least cost method, identifying the standard times of the activities or simply to improve the current system by training (Thomas, et al., 1990).

A thorough work study consists of two parts namely a methods study and a work measurement study. A methods study is also referred to as a motion study and investigates the way in which a task is performed and seeks to find the preferred way of executing the work (Thomas, et al., 1990). A work measurements study is a study of time and is executed to determine the standard time within which a task is executed (Thomas, et al., 1990).

In order to understand a productivity measurement we will discuss different techniques which can be used to measure productivity.

4.1.1 Models that define Productivity

Thomas, Maloney, Malcom, Horner, Smith, Gary, Handa, Vir and Sanders (1990) identify three different models by which productivity can be measured. These models are described in the following sections

4.1.1.1 Economic models

The economic models are mostly used by commerce departments and other governmental agencies. The reason being, that the units with which the equations are populated are changeable to financial terms. A typical equation used can be seen in Equation 4.1 (Thomas, et al., 1990). The equation gives a fraction called the total factor productivity (TFP) and the output and input are expressed in a specific currency such as dollars or rand. To make Equation 4.1 more understandable to a South African context it can be simplified to Equation 4.2 (Thomas, et al., 1990).

$$TFP = \frac{Total\ output}{Labour+Materials+Equipment+Energy+Capital} \quad \ldots\ldots \quad 4.1$$

$$TFP = \frac{Rand\ value\ of\ output}{Rand\ value\ of\ input} \quad \ldots\ldots \quad 4.2$$

Although this equation is effective to calculate TFP, it is not very comprehensive and is often used in policy-making or broad programme planning (Thomas, et al., 1990).

4.1.1.2 Project-Specific models

Project specific models are more tailored for a specific project. With this model the productivity is measured in terms of money value per unit of measure. Equation 4.3 is a typical example of an expression of square feet per cost (Thomas, et al., 1990). Equation 4.4 is a simplification of Equation 4.3 and it shows the money value versus the units produced clearer (Thomas, et al., 1990).

$$Productivity = \frac{Square\ Meters}{Labour+Equipment+Materials} \quad \ldots\ldots \quad 4.3$$

$$Productivity = \frac{Square\ Meters}{Total\ rands\ spent} \quad \ldots\ldots \quad 4.4$$

This expression of productivity is also used by many design professionals (Thomas, et al., 1990).

4.1.1.3 Activity-Orientated models

A more specific approach to determine productivity is with activity-orientated models (Thomas, et al., 1990). This approach is often used by contractors in generic activities. The units used are often cubes, tons and square meters. The activities measured include specific activities such as formwork, concrete placing, and steel reinforcement (Thomas, et al., 1990). When using the above mentioned activities, it makes sense to use labour productivity as a measure of productivity, because these activities are commonly executed by human labour. Dozzi and AbouRizk (1993) regard productivity measurements expressed in terms of units delivered per person hours as the most accurate measure for construction use. Equation 4.5 gives an example of a typical activity orientated productivity measure (Thomas, et al., 1990).

$$Labor\ Productivity = \frac{Volume\ produced}{Total\ work\ hours} \qquad \text{4.5}$$

It is important to note that labour productivity is a measure of the overall effectiveness of an operating system in utilizing labour, equipment and capital to convert labour efforts into useful output, and is not a measure of the capabilities of the labourer alone. For example, by investing in a piece of new equipment to perform certain tasks in construction, output may be increased for the same number of labour hours, thus resulting in higher labour productivity (Hendrickson & Au, 2008).

The hours worked itself can prove to be difficult to interpret. Firstly, the significance of the labour productivity value obtained can be largely influenced by the interpretation of the total work hours. Secondly, there can be discrepancies between hours paid, hours worked effectively, hours spent working ineffectively and also time spent not working at all. Thus, these interpretations of the denominator can largely influence the relevance of the value obtained (Thomas, et al., 1990).

A challenge facing detailed productivity measurement approaches, such as breaking down the total work hours into sub groups, is the capturing of detailed data. What is also important is the degree to which the study should be done for the contractor to benefit from the processed data. It is unhelpful if the contractor knows how much time the workers spend not working, yet is unable to save money by justifying the fact of not paying labourers for those lost hours. Rather, contractors are interested in the cumulative average productivity value that will apply throughout the activity (Thomas, et al., 1990). Researchers on the other hand are interested in productivity values in shorter periods of time for a given set of conditions (Thomas, et al., 1990). It is therefore important to identify what policies and legislation restrict the contractor in his actions towards improvement. Labour legislation and policies are therefore investigated as part of the macro area of labour productivity and discussed in section 4.3.

When tendering for projects the cumulative average productivity values that will apply throughout the activity are very important and it is an art to correctly estimate these values to make the project more profitable. For this reason contractors also make use of performance factors. The performance factor is the ratio between the estimated unit rates of labour productivity and the actual labour productivity rates. Equation 4.6 shows how to calculate the performance factor. The performance factor will provide valuable information to the contractor to improve his productivity values for specific activities in the future (Thomas, et al., 1990).

$$Performance\ factor = \frac{Estimated\ unit\ rate}{Actual\ unit\ rate} \quad \text{4.6}$$

Now that a number of productivity defining models have been discussed, the focus will be on how productivity is measured. The following section will identify six different methods of measurement, ranging from simplistic to highly advanced methods. The discussions of these different methods will serve a dual purpose in this thesis document. The first purpose is to provide information to understand productivity measurement in construction. Secondly the discussions are done to such an extent that the information can also be used as reference material to implement these methods for productivity measurement.

4.1.2 Measuring Productivity

One of the challenges of measuring productivity is to capture data to conduct the different studies mentioned. Current data capturing methods include video photography, time lapse photography, stopwatch timing and work sampling. All of these methods are currently used in construction and research is conducted to improve the efficiency of these methods (Gong & Caldas, 2011; Jog *et al.*, 2010; Son *et al.*, 2010).

In the previous section different models were used to define specific types of productivity. Measuring productivity makes use of different techniques to determine specific elements of productivity. There are various methods used to measure and interpret the work performed and effectiveness of a construction crew. This study investigated six measuring methods namely:

1.) Field rating
2.) Work Sampling
3.) Five minute rating
4.) Method productivity delay method
5.) Charting techniques
6.) Simulation modelling

These six methods are explained and summarised in Appendix E for implementation purposes. The main pitfalls of each method are stated in Chapter 5.

4.2 Factors influencing labour productivity

In section 4.1 general productivity in construction was discussed. The discussion included an investigation of different models used to define and measure productivity. In this section the focus will be on an investigation into what influences productivity and the factors will be grouped in specific categories.

Dozzi & AbouRizk (1993) suggest that improvement of productivity on a construction project is better understood if a construction project is seen as a complete system. This system comprises of inputs such as materials, personnel, management and equipment as seen in Figure 4.2. Each of these inputs is measured in different units and used in different quantities. The construction project, as a system, consumes the inputs in order to deliver outputs. These outputs are called production units and in the case of a construction project, it can be a building, pipeline, road or any other end product of a construction project. The production unit is subject to the system used. If the system is defined by an activity, the production unit can be a laid brick, a standing wall or a complete building. The production units are therefore defined by the level and detail in which the productivity measurement is calculated.

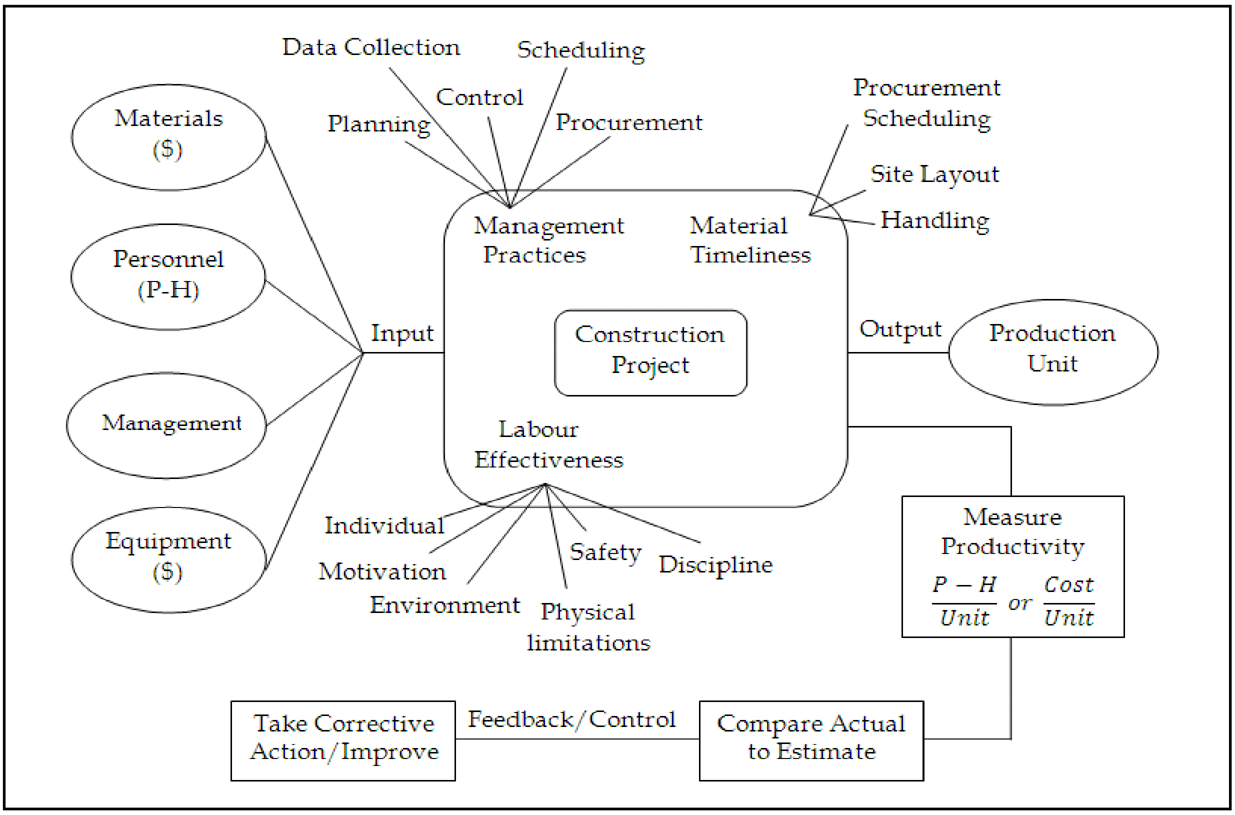

Figure 4.2 - System for productivity improvement (Dozzi & AbouRizk, 1993).

Within the system, there are factors influencing the productivity. In Figure 4.7, these factors are grouped in three main categories namely: Management practices, Material timeliness and Labour effectiveness.

The survey conducted by the CMP delegates of 2012 discussed in Chapter 3, showed that low productivity of labourers is the area of largest concern. Therefore, investigating the labour effectiveness category in isolation would prove to be sufficient at first glance. However, because a construction project is seen as a complete system, the effects of the other factors grouped in the other two categories also play a role in the overall productivity. This statement is supported by Hendrickson and Au (2008) who stated that it is not only the labour capacities alone that influence the productivity of labour on a construction site.

According to Hendrickson and Au (2008) labour productivity is a measure of the effective utilization of labour, equipment and capital, and not only the measure of the labour capacities alone. Hendrickson and Au (2008) stated that all three these elements work together to generate a labour based output. For this reason factors within all three the influence categories are investigated to get a better picture of most of the factors influencing productivity. The following sections will investigate the three different influence categories identified in the *productivity improvement system* in Figure 4.2. The categories are management practices, labour effectiveness and material timeliness.

4.2.1 Management Practices

In this section five factors are investigated that are primarily influenced by management or the lack thereof. This includes the factors of planning, data collection, control, scheduling and procurement.

4.2.1.1 Planning

Work distribution and planning of the overall job, play an integral role in the productivity of site operations. Planning of the construction phases, such as designing before construction drawings are issued, is important to ensure minimal rework and design changes. The specific trades involved with a part of the construction should only be called to site when the preceding trade has made sufficient progress to prevent waiting times. Planning of the availability of materials is also important to ensure that there is a constant work flow on site and no delays are caused by waiting for materials. Overall good planning is a motivator to the workforce because momentum can be kept while aiming to complete specific tasks without interruption.

Change orders can require the contractor to make use of a different construction method because the quantity of work changes. Additional work or change orders also influence productivity due to the fact that the momentum of workers is broken and that a stop-go phenomenon will exist. A change order has major influences on productivity and should be carefully monitored by the contractor.

Variations could be seen as an opportunity to increase profit margins due to the lack of competitive bidding for the specified work. The knock on effects of the change should, however, be carefully measured to make sure that there is indeed benefit in accepting the variation order.

4.2.1.2 Data collection

According to El-Omari and Moselhi (2009), accurate and timely data collection plays an integral part in taking corrective actions to assist in delivering projects on time and within budget. There are three main reasons why data collection is important and these are to 1) monitor the progress of the project, 2) to satisfy all of the contract requirements and 3) to track the productivity for project management and profitability purposes (Allen & Alexander, 2013).

4.2.1.3 Control

Security is used as a control mechanism on construction sites in order for management to know if illegal workers, weapons, drugs or tools leave and enter the site (Keyte, 2013). Security on a large construction site has an effect on labour productivity. The productivity is negatively influenced by time lost during security measures when entering and leaving restricted areas on the workplace (Intergraph Corporation, 2012). Toolbox checks and transporting labourers to site also have an influence on the productivity of labourers (Intergraph Corporation, 2012). In this case increased control creates a loss in productivity.

However, Katz, Saidi and Lytle (2008) stated that having cameras on a construction site enhances the situation awareness by tracking material equipment and other resources. This helps with progress reports and in providing automated alerts in potential hazardous situations (Katz, et al., 2008). This means that cameras can improve the control on site as well as benefit productivity and thus, increased control is not only regarded as a productivity inhibitor.

Rework is when work has to be done for a second time or when corrections have to be made due to work failures that do not comply with specifications. Projects rarely make provision for rework and time and resources spent on this type of work, directly reduce the expected profits. The rework is caused by various sources and includes poor instructions to labourers, inadequate training of workers and supervisors, poor supervision, incorrect tools and inadequate materials, among others.

Rework management is a form of control during construction because it equips the managers of the project to implement mitigation actions and obtain direction when dealing with tough rework issues (Business Electronics Soldering Technologies, 1998). Rework management helps to keep the rework operations somewhat constant and manageable. This in turn helps to reduce the company’s vulnerability to adverse effects on productivity (Business Electronics Soldering Technologies, 1998).

The transitioning from one work task to another task during a day's work is something that often occurs in a project (Adrian, 2013). This transition of teams has been observed to happen ineffectively and that time is lost to finish the existing task and start the new task (Adrian, 2013). Given this lack of a goal orientated approach to new tasks, motivation, and thus productivity, of workers are low. According to Adrian (2013) this is something management can improve with more effective control without neglecting the reward a worker is entitled to after the successful completion of a task.

The labourer-supervisor ratio is the relationship between the amounts of supervisors needed for a given amount of labourers. The amount of labourers can be regulated by policies and work rules or legislation; however, the amount of supervision needed is based on the discretion of the contractor (Adrian, 2013). Too much supervision could prove to be un-economical whereas too little supervision could have a negative impact on the effectiveness of the work and productivity (Adrian, 2013). Management should also take care to not require teams of labourers to work in many different places at the same time. Dispersing the tasks geographically will result in time lost travelling and organising materials and sufficient supervision (Adrian, 2013).

From the discussion above it can be deduced that control on a construction site can have both positive and negative effects on productivity. It depends on how the control is achieved and what mechanisms are used to have control.

4.2.1.4 Scheduling

Scheduling can be divided into a number of areas that have an influence on productivity. Although these areas of scheduling are discussed separately, they can occur together and have a combined effect on productivity. These areas are stop and go, ripple effect, shift management and concurrent operations.

Stop and go is a result of bad scheduling and occurs when a crew, or part thereof, is forced to stop their current activity and move to another activity due to factors such as lack of instructions, resources or a fixed schedule of works. Approval of workmanship is another factor that causes stop and go operation and plays a big role in maintaining productivity (Bothma, 2012). Adrian (2013), states that almost 10% of time is non-productive due to the fact that craftsmen wait for instructions after completing a task before the end of the day. Management and supervisors must, therefore, focus on having a secondary task assigned to the labourers so that this task can be started in the event that the craftsmen are waiting for an instruction. Holidays and public holidays add to the effect of start stop operations and management should try and finalise major activities before such a break so that the lack of momentum, experienced after the break, does not influence the activity (Intergraph Corporation, 2012).

Ripple effect is another area that falls under scheduling and is defined as the unforeseeable effects of a change that occurred (Long & Carter, 2013). These effects are often only seen after final profit and loss statements are drawn up (Long & Carter, 2013). The ripple effect is therefore a management related factor that influences productivity, but is very hard to eliminate except if minimal changes occur regarding the schedule of the project (Long & Carter, 2013).

Managing shifts within the schedule of a construction project is a factor that influences the productivity of labour because it changes the daily pattern of the labourers. Multiple shifts occur when there is more than one group of workers working on a specific project operation but with different working hours (Intergraph Corporation, 2012). Multiple shifts are sequenced after each other and the next shift starts with a new group of workers. Some trades work well under multiple shifts, whereas other trades experience a drop in productivity (Intergraph Corporation, 2012). Simplistic trades with a small learning curve improve productivity with multiple shifts. However, it is found that precision and technical trades experience a decrease in productivity. Shift work influences the labourers' sleeping and eating routine. It has been proved that the human body only adapts to these changes within 30 days. Shifts are often rotated every 30 days for fairness but this reduces the productivity due to the adaptation each worker has to undergo each month.

Concurrent operations influence the schedule of management in a negative way and lowers productivity (Intergraph Corporation, 2012). Concurrent operations occur when small tasks are added after or in between other tasks that have been finalised in a planned schedule. This happens without compensating for these tasks in the schedule and creates a higher workload in the same planned schedule (Intergraph Corporation, 2012). Workers lose motivation due to the lack of definite goals and milestones reached according to schedule.

Adrian (2013) recognised during his study that tasks on the critical path do not show as if they have a higher priority when observing how the workers perform their work. Management cannot possibly encourage workers to push to finish every activity because the work is just too much (Adrian, 2013). However, tasks on the critical path should be identified to the labourers as well so that they can work with a sense of urgency.

However, even a sense of urgency might not be enough to catch up with time lost on the critical path and overtime is seen as the solution. Overtime is defined as the time worked in excess of 40 hours a week. A 40 hour week is stated to be the optimal amount of hours to achieve the best progress, and working more than this amount reduces the output rate. Some studies prove that after nine 50 hour weeks of work, one 50 hour week could have an output rate less than a standard 40 hour week without overtime. Table 4.1 shows the relationship of the amount of hours worked per week and the inefficiency factor. The relationship is shown for short and long term effects and for weeks with different amount of work days.

Table 4.1 - Relationship of overtime and the inefficiency factor (Dozzi & AbouRizk, 1993).

Days per week	Daily hours	Weekly hours	Inefficiency factor			
			7 Days	14 Days	21 Days	28 Days
5	9	45	1.03	1.05	1.07	1.1
5	10	50	1.06	1.08	1.12	1.14
5	11	55	1.1	1.14	1.16	1.2
6	9	54	1.05	1.07	1.1	1.12
6	10	60	1.08	1.12	1.16	1.21
6	12	72	1.13	1.2	1.26	1.32
7	8	56	1.1	1.15	1.2	1.25
7	9	63	1.12	1.19	1.24	1.31
7	10	70	1.15	1.23	1.3	1.38
7	12	84	1.21	1.32	1.42	1.53

Scheduling can, therefore, be seen as a major factor that influences productivity on a construction site because of the amount of factors that can be categorised under scheduling. Another managerial factor that goes hand in hand with scheduling is procurement.

4.2.1.5 Procurement

Procurement can be divided into different areas that all have an influence on productivity. The first of these areas is stacking of trades followed by crowding, late crew build-up and overstaffing.

Stacking of trades is when two or more trades are forced to work within the same geographical area at the same time due to bad scheduling. This creates congestion and the work area becomes a space where unsafe practices are exercised. Productivity is lost due to the difficulty of moving and transporting materials in a limited area. It has been proven that even the perception of a smaller work area can have productivity losses as an effect.

Crowding is similar to stacking of trades but is a result of accelerated work due to schedule pressure. Crowding is measurable and is calculated by using standards which specify the accepted area needed to perform tasks in. If an area is acceptable to house 13 workers and 15 workers are working in that space, the overcrowding is calculated as 2/13 = 15.38%. In Figure 4.3 a 15.38% overcrowding results in a 4.5% loss off efficiency. This is equivalent to a 4.5% increase in the time it would have taken to do the task in normal special requirements.

Construction usually makes use of groups of workers that work in teams to perform tasks. This requires communication between team members and the supervisors in charge of them. It has been proven that effective, open, two-way communication improves teamwork because it gives the crew a chance to communicate problems and solutions that are tailored to their needs, to management. This empowers the crew members and gives their opinion meaning. Teams are built up to get to a specific size with regards to the number of crew members in the team.

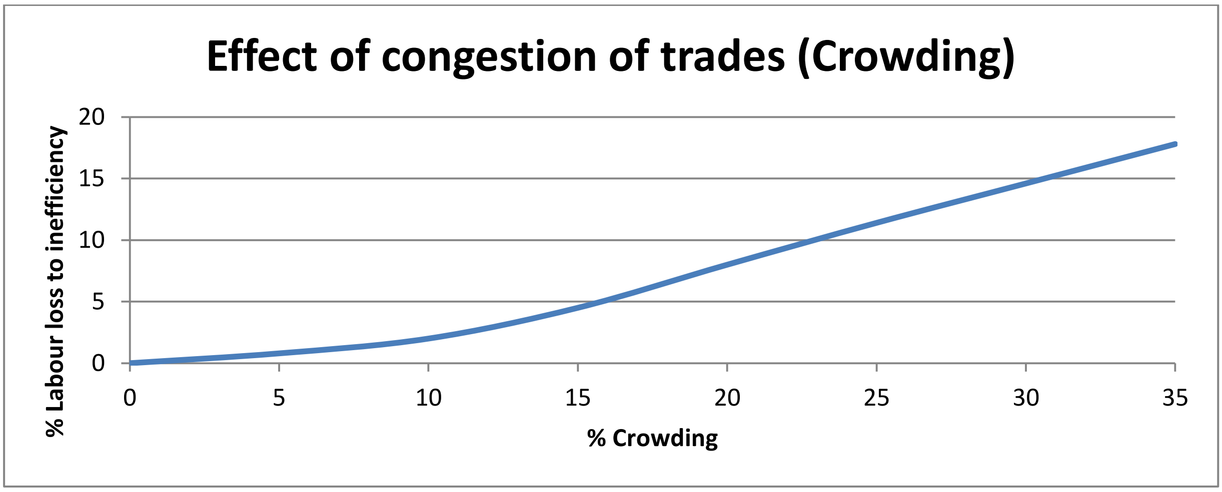

Figure 4.3 - Effect of congestion of trades (Crowding) (Dozzi & AbouRizk, 1993).

Late crew build-up is when the number of crew members is altered from what was planned initially (Intergraph Corporation, 2012). This causes a slower build-up of the manpower loading due to competition for resources. Manpower loading is when workers are assigned to specific tasks or operations in the project schedule (Business dictionary, 2013). Late crew build-up is also described as a lack of team cohesion and is found to have negative effects on productivity of labourers (Intergraph Corporation, 2012).

The statements above stated that crew build-up should happen as quickly as possible; however the managers in charge of crew build-up must be aware of the crew sizes. The manager should not mistakenly think that the crew size should be as big as possible, as soon as possible (Intergraph Corporation, 2012).

Dozzi and AbouRizk (1993) describe overstaffing as the occurrence where more workers are assigned to a task, than are required to work productively. The effects of overstaffing include the loss of productivity due to the imbalance between the acceptable rate of progress and the highest level of productivity.

The optimal crew size is the minimum amount of crew members that can, economically, complete the task within the scheduled time. Figure 4.4 shows how the efficiency of the total crew is influenced with the increase of members above the optimum number.

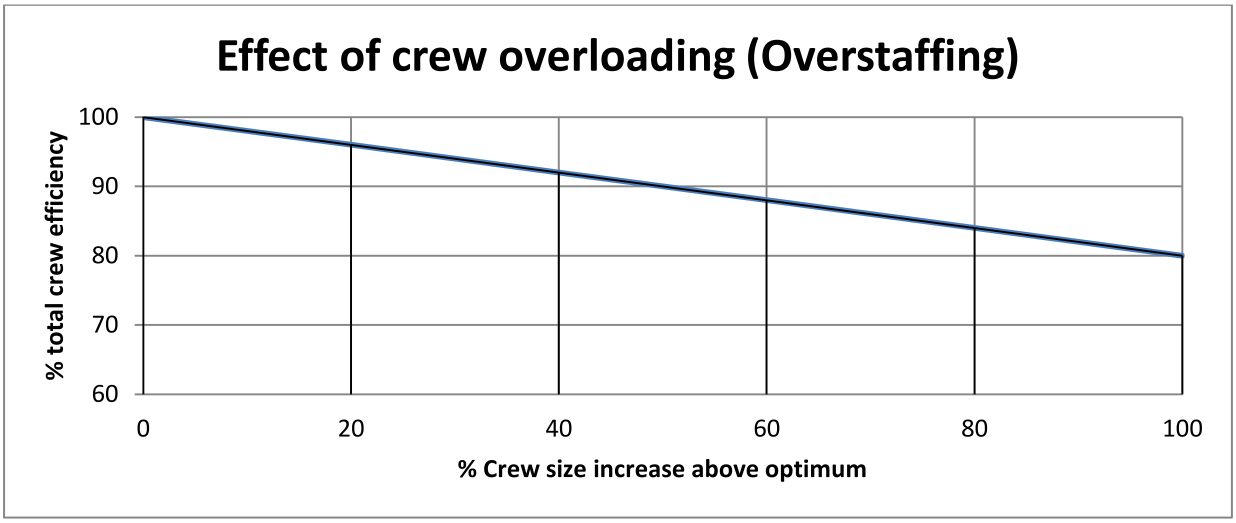

Figure 4.4 - Effect of crew overloading (Dozzi & AbouRizk, 1993).

Matching the actual crew size with the crew size required, continues to be a source of loss in productivity according to Adrian (2013). Even though estimators have experience in estimating the amount of work hours needed to perform tasks, the holistic picture of amount of labourers on site is not always accounted for (Adrian, 2013). More effort needs to be put into understanding how many workers are on site at a given time and link this process with resource management to ensure that the correct amount of workers are on site.

4.2.1.6 Summary of management practices

This section discussed various management related factors that influences productivity on a construction site. Effective planning in terms of phase sequence was proven to reduce the rework percentage. The monitoring of the progress made by specific trades proved to reduce the time wasted, by subsequent trades, caused by waiting for work. Accurate and timely data are important aspects of data capturing that could reduce the magnitude of negative effects by giving real-time productivity measures. Control was seen to have the ability to have positive and negative impacts on productivity depending on the mechanisms used. Scheduling is a factor that management should value in order to achieve good productivity on site. The reason for this statement is because there are many areas, categorised under the scheduling factor that could negatively influence productivity. These areas include stop-go operations, ripple effects, multiple shifts, concurrent operations and overtime. These areas were shown to have negative effects on productivity if there is a lack of management assigned to these areas. Just as with scheduling procurement also has a number of areas that could negatively influence productivity. Procurement areas include stacking of trades, crowding, late crew build-up and overstaffing. These areas could all negatively influence productivity if management does not implement a procurement management plan.

4.2.2 Labour Effectiveness

Labour effectiveness is another category, within the *productivity improvement system,* that influences productivity. This category includes factors mainly directed at the human qualities of labourers. An investigation was made into how the labourer, as a person, adapts to different changes and environments while performing his or her work. There are six categories investigated under this category and include the qualities of the individual, safety, motivation, environment, physical limitations and discipline.

4.2.2.1 Qualities of the individual

The attitude and personality of the labourer can play a role in the productivity of the other crew members. Dozzi and AbouRizk (1993) are of the opinion that a worker with an optimistic and positive attitude is more likely to come up with innovative and imaginative solutions in the workplace. Productivity can be improved by individuals with a sense of humour that are friendly, caring and considerate. This is because some humour in the workplace brings peoples' spirits up and relieves stress and in turn enhances teamwork.

Labourers who are safe and healthy could be beneficial to the project's productivity because fewer instances of down time caused by accidents or injuries will occur. Labourers who are creative can contribute to productivity to a large extent due to the potential practical solutions they come up with. These solutions are tailored to benefit the crew members in some way and have positive influences on task productivity.

When an individual does a task for the first time he will take longer to complete it due to the fact that he or she is learning how to execute the task. After a few repetitions of performing the same task, the amount of time needed to perform the task will decrease. This phenomenon is called the learning curve and Figure 4.4 shows how the percentage of time required to complete the task drops as the cumulative units increase. The cumulative units refer to the amount of times the task was performed. In the case of a mason the units could be the amount of bricks laid. The time to produce a unit will, however, only reduce until it stays at a relative constant time. Figure 4.4 shows the plateau when the cumulative units are at 18. This plateau is representative of the minimum time needed to perform the task. The reduction in time to produce a unit is due to the fact that the individual has learned how to optimise the completion of the same task. This phenomenon is described as the learning curve and is a mechanism that can be beneficial in terms of productivity with tasks that require repetition.

The opposite can also happen when the individual "unlearns" how to perform the task optimally. This happens to individuals when there is an interruption in the repetition cycle of completing tasks. This unlearning effect also happens to individuals that are constantly shifted to other areas of work and constantly have to learn how to perform new tasks. Shifting workers to other work areas has negative effects on the productivity of the individual and the project.

Figure 4.5 shows how an interruption occurred after the individual had completed a similar task 4 times. The time needed to perform the task had already dropped to 85% of the initial time when the interruption occurred. After the interruption, work was continued and the time needed to perform the task raised to 93% of the initial time needed to complete the task. This shows that after the interruption the individual had unlearned how to optimise the time needed to complete the task. The distance between the solid - and dotted curved line in Figure 4.5 shows the difference in time needed due to the unlearning effect the interruption created.

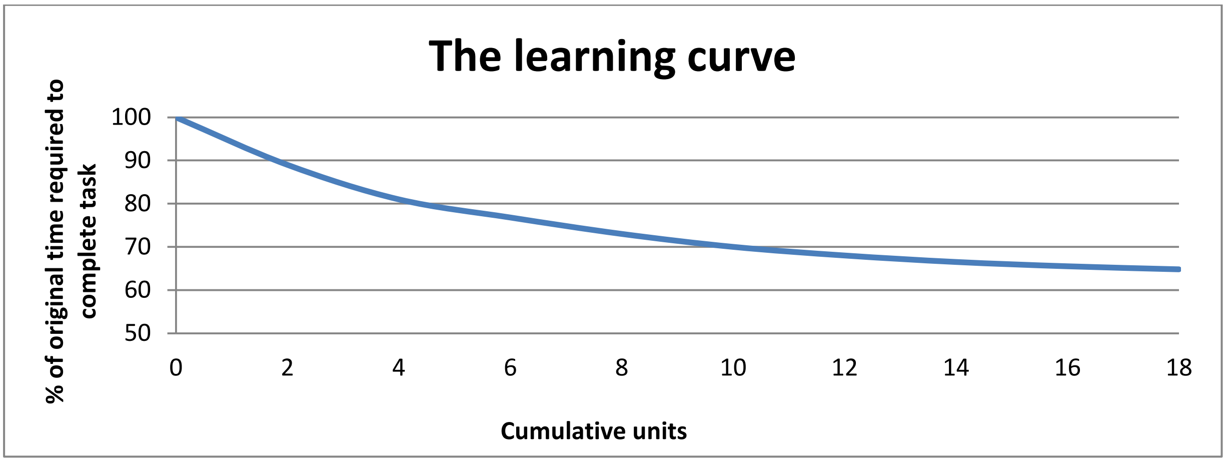

Figure 4.4 - The learning curve showing reduction in time needed with increase of tasks completed (Dozzi & AbouRizk, 1993).

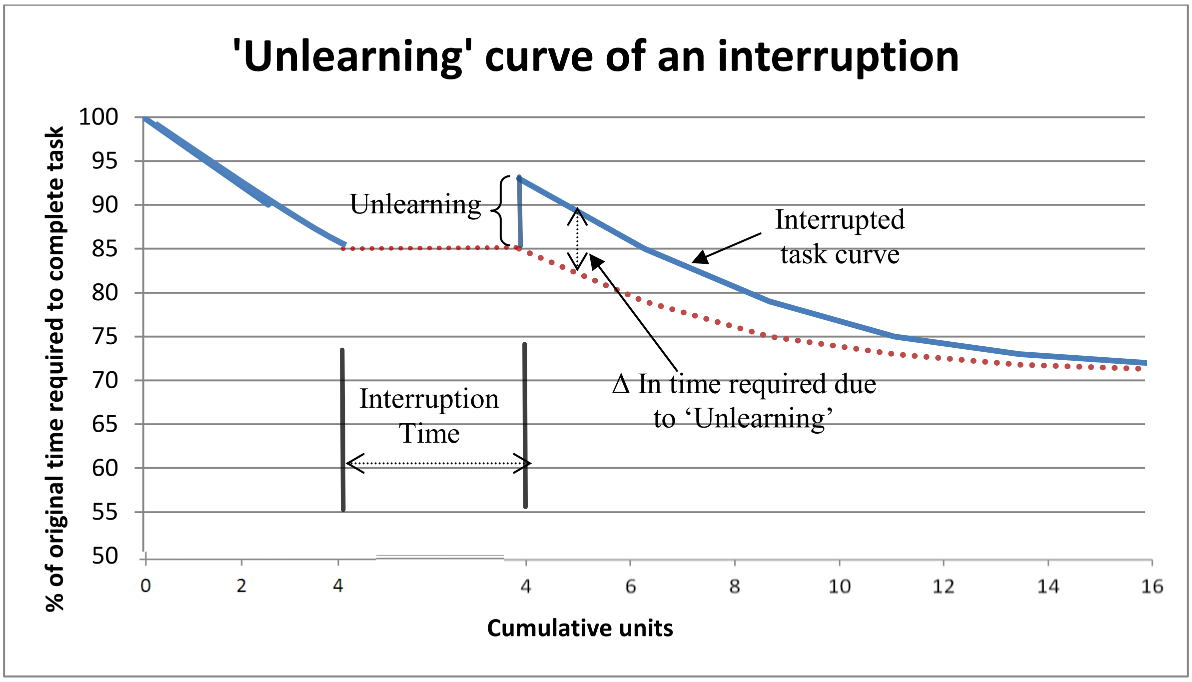

Figure 4.5 - The unlearning effect when an interruption occurs (Dozzi & AbouRizk, 1993).

4.2.2.2 Safety

Safety on a construction site is not only a moral responsibility of management but has also proved to have a great economical impact on construction. Construction companies do not only spend money to enhance safety but they also benefit from a safer site. A safer site has advantages that include the motivation of the workforce and the reduction of accident costs. The workforce has shown to perform better if genuine concern is given to their well being. Accident costs are broken into injury compensation, liability claims and loss of property. These amounts could add up to be a large amount of money.

Safety is often neglected when crew are pressured with a productivity problem. However, this statement does not imply that neglecting safety will increase productivity. In fact, it is stated that a safe site can improve productivity due to the motivation and high awareness of the workforce. Dozzi and AbouRizk (1993) therefore recommend that safety on a construction site is an inevitable responsibility and that it can save time, cut accident costs and increase productivity.

4.2.2.3 Motivation

Motivation plays a big role in the effort an individual puts into their daily work. Productivity SA (2012) estimates that the productive difference between a motivated individual and an unmotivated individual can be as much as 60%. Various factors influence the motivation of the worker and many are described in other categories within the whole of section 4.2. Motivators are factors that improve the motivation of the individual worker and thus help to improve productivity. The motivators are summarised in Table 4.2 and are based on Frederick Herzberg's seven principles for enhancing motivation.

Table 4.2 - Frederick Herzberg's seven principles for enhancement of motivation (Dozzi & AbouRizk, 1993).

Principle Number	Description
1	Remove some mechanisms of control, but keep measures of accountability.
2	Accountability of individuals should be increased for work done by them.
3	Assign a complete natural unit of work to a worker.
4	Additional authority should be given to an individual whilst he or she is managing his or her own task.
5	Periodic reports should be made available to the individuals performing the work.
6	New and more difficult tasks should be introduced to the team or individual.
7	Specific and specialised tasks should be assigned to individuals so that expertise is achieved within these tasks.

De-motivators are factors that negatively influence the motivation of the individual and consequently reduce productivity. These factors include overtime, overstaffing, stacking of trades, crowding multiple shifts and stop-go operations. These factors are described within Appendix E. Ng, Skitmore, Lam and Poon (2004) believe that by just removing some of the de-motivators rather than implementing motivators can have a big influence on the productivity improvement of a project. Some of the de-motivators they identified with a survey can be seen in Table 4.3.

Table 4.3 - Predominant de-motivators of civil engineering (Ng, et al., 2004).

De-motivators	No. of affirmative responses				% of affirmative responses				
	Plant Operator	Carpenter	Steel fixer	Total	Plant Operator	Carpenter	Steel fixer	Total	Rank
Rework	24	22	11	57	55	58	48	54	1
Overcrowded work areas	26	19	9	54	59	50	39	51	2
Crew interfacing	18	19	7	44	41	50	30	42	3
Tool availability	12	18	12	42	27	47	52	40	4
Inspection delays	12	17	13	42	27	45	57	40	4
Material availability	10	19	9	38	23	50	39	36	6
Foreman incompetence	16	12	9	37	36	32	39	35	7

From Table 4.3 it can be seen that having to do rework is a major de-motivator and influences the labourer's morale to a great extent. Many of these de-motivators have been discussed in the preceding sections. Rework was touched on in section 4.2.1.1 which discussed the planning factor that influences productivity. Overcrowded work areas and crew interfacing were discussed in section 4.2.1.5 which discussed procurement on site. Inspection delay is another area that was briefly mentioned in section 4.2.1.4 and forms part of the scheduling factor that influences productivity. Tool and material availability will be discussed in section 4.2.3.

Table 4.3 therefore shows many resemblances to the other factors identified by other references in prior sections. However, according to a survey conducted by Lim and Alum (1995) in Singapore, the lack of recognition is one of the main factors that contributes to low productivity levels on construction sites. This factor coincides with element 5 in Table 4.2 which is suggested to raise motivation levels. Higher motivation, according to Productivity SA (2012), also improves productivity with great measure.

4.2.2.4 Environment

The work environment is another factor that influences the labour effectiveness on a construction site. In order to create an environment for motivated work, the site environment must make the labourer feel valued by providing basic needs. These needs include drinking water, sanitary facilities, site access, parking and protective gear. Furthermore, the workspace should be safe, healthy and organised. It has been proved that labourers who feel safe will work more productively. Organising and keeping the work area and the site clean is stated to be worthwhile due to the efficiency gains it produces.

It is not only the working environment but the external environment that plays a role in the way labourers perform on site. Table 4.4 shows the relationship between temperature, relative humidity and productivity. It can be seen from the table that optimal productivity regions are within temperatures from 4-21˚C and a relative humidity between 20-60%. For this reason the climate and weather during certain times of the year influence productivity on the site. Shorter daylight hours also play a role in productivity and are connected to the seasons of the year. For this reason climate effects need to be considered when productivity is measured, especially when rain occurs. Noise also plays a role in productivity of labourers and could even become a safety hazard if precaution with regards to protective gear is not taken. Noise can influence the quality of work more than it influences the amount of work done. It has been proved that background music below 90 decibels will increase the performance of work.

Table 4.4 - Productivity percentage given relative humidity and temperature (Dozzi & AbouRizk, 1993).

	Temperature ˚C												
Relative Humidity%	-23	-18	-12	-7	-1	4	10	16	21	27	32	38	43
90	56	71	82	89	93	94	98	98	96	93	84	57	0
80	57	73	84	91	95	98	100	100	98	95	87	68	15
70	59	75	86	93	97	99	100	100	99	97	90	76	50
60	60	76	87	94	98	100	100	100	100	98	93	80	57
50	61	77	88	94	98	100	100	100	100	99	94	82	60
40	62	78	88	94	98	100	100	100	100	99	94	84	63
30	62	78	88	94	98	100	100	100	100	99	83	83	62
20	62	78	88	94	98	100	100	100	100	99	82	82	61

The next section will discuss the physical limitations of human labourers and how tasks influence their productivity. This is the second last section that will be discussed within the labour effectiveness area of the investigation.

4.2.2.5 Physical limitations

Physical limitations are what makes labourers rest during construction and why it is necessary to have tea- and lunch breaks during a work day. According to Oglesby, Parker and Howell (1989) an average young male can produce energy of 21kJ/min. This is known as the potential to perform work. Approximately 4.18kJ/min is needed to live and keep the metabolism active. Just like a dam or reservoir the human body has a storage capacity. The storage capacity, according to Oglesby *et al.*(1989), is 10.5kJ. An average construction task that requires 17.24kJ/min can, therefore, only last for 25 minutes before the worker needs to rest. If, however, the task only requires 16.82kJ/min (21kJ/min minus 4.18kJ/min) the worker could sustain the work (Oglesby, et al., 1989).

The nutrition that the individual gets while working and after hours influences his or her strength and ability to function on site (Oglesby, et al., 1989). Research has proved that malnutrition is prevalent in sub-Saharan Africa and this could have a negative effect on the ability of the worker to function productively (Svedberg, 1990). The use of alcohol on site, or the presence of intoxicated labourers on site, is realities from time to time and this also influences efficiency of the worker (Lim & Alum, 1995). Given the physical limitations and possible malnutrition of the workers, personal breaks over lunch and tea breaks must be monitored as this was identified by Adrian (2013) and Dozzi and AbouRizk (1993) as a major productivity inhibitor. Late starts and early quits may seem to be short time losses and not relevant. However, Adrian (2013) added that the typical late starts and early quit losses occurring on a construction site in a day need to be put into perspective and added over the project duration. A ten minutes late start in the morning, added to ten minutes lost at tea time as well as lunch, and a further ten minute unnecessary early finish sums up to a 40 minute loss of time. When put into perspective, this amount is almost 10% of the daily work time and this could mean that a loss of 10% is experienced due to these late starts and early quits.

4.2.2.6 Discipline

Absenteeism plays a big role in lowering productivity due to the fact that crew members waste time waiting for replacements. Time is also spent transporting the replaced workers from different locations and supervisors lose time when reassigning work and balancing resources. The top six reasons for absenteeism according to Dozzi and AbouRizk (1993) are listed in Table 4.5 and are ranked in order of importance. Turnover in terms of workers on site is another issue that influences productivity in a negative way and the cost is estimated at 24 person-hours for each resignation. Reasons for turnover are ranked in terms of importance in Table 4.6.

Table 4.5 – Top six reasons for absenteeism (Dozzi & AbouRizk, 1993).

Order of importance	Reason for absenteeism
1	Personal or family illness
2	Overall management is poor
3	Supervision on poor standard
4	Travel distance from house is long
5	High rework amount
6	Working conditions are unsafe

Table 4.6 - Reasons for turnover (Dozzi & AbouRizk, 1993).

Order of importance	Reason for turnover
1	Tools and Equipment are inadequate
2	Surveys of on-site work by owner are excessive
3	Planning is poor
4	Overall management is poor
5	Supervision not up to standard
6	Another job offers overtime
7	Relationship with boss is unsatisfactory

4.2.2.7 Summary of labour effectiveness

In this section we discussed the factors, categorised under labour effectiveness, which influence productivity on a construction site. The discussion showed that the personality of the labourers play a role in the morale of the crew of labourers and that the learning curve plays a big role in terms of time savings in a sustained productivity. It was also shown that safety on a construction site is an inevitable responsibility and that it can save time, cut accident costs and increase productivity. During the discussion it was seen that many of the de-motivators for labourers are areas already discussed as factors that influence productivity. It can therefore be stated that, if some of the negative factors are mitigated, the motivation of workers will improve. The environment, within which the labourers have to work is important and both the working environment and the external environment should be considered when productivity is monitored. The physical limitations of labourers are real and foremen and supervisors need to remember the physical nature of the work. Discipline in terms of absenteeism and turnover is seen to be a major factor during construction and causes the project to lose productivity and valuable man-hours.

4.2.3 Material Timeliness

Hendrickson and Au (2008) state that material handling should be attended to with great attention in order to reduce costs. However, this section will investigate how material and the availability thereof influence productivity. The areas that will be investigated within this category include handling, site layout and procurement scheduling.

4.2.3.1 Handling

Tool shortage is when the tools, needed to do tasks, are not available or not adequate for the job (Hendrickson & Au, 2008). Not only is this the main reason for absenteeism from site but it plays a role in the timeliness in which tasks are performed. Communication, in terms of when materials will be needed, influences the time labourers have to wait for materials or equipment. Finding material and tools is also a factor that largely influences productivity because of wasted time waiting. This loss of productivity reflects negatively on the labourers. Workers need clear and exact information on how to execute the task in order to contribute to the success of the project.

Communication that flows in two ways has improved productivity in Japan, where a bottoms-up approach to management is taken. For this reason it can be stated that in order to improve the handling of materials, timely and open communication is needed. Within the data capturing section in 4.2.1.2 it was seen that if timely data were given, it could be used to decrease negative effects.

4.2.3.2 Site layout

Job site planning should include placing facilities in such a way to maximise efficient times and ease of access. This will greatly influence productivity on site, depending on the size and complexity of the site. Planning of the site should commence early in the project life cycle to ensure that all factors are taken into account. Special attention should be given to environmental issues, different trades present, access points, and the synchronisation of these with the schedule. Offices, lunch and tea rooms and sanitary facilities also need to be placed at strategic places to ensure easy access and that time is not lost travelling to and from the facilities.

Mobilizing and demobilising labour teams to different sections of the project cause time loss and a reduction of productivity. These changes should be managed so that the disruptions are minimised and work can flow as naturally as possible.

4.2.3.3 Procurement scheduling

Procurement scheduling refers to a strategic sequence in which procurement happens. This method of procuring has benefits and ensures that risks regarding materials on site are minimised (Sun, et al., 2010). Material Procurement Planning (MPP) is a material-specific method of procurement scheduling. MPP can minimise the cost of the materials if material prices fluctuate over time but can be used to minimise waiting time or work flow disruptions due to the unavailability of materials (Sun, et al., 2010).

4.2.3.4 Summary of material timeliness

The material timeliness category includes three main factors that have an influence on the productivity in construction. The discussion of these areas showed that tool shortage not only causes lost time but is one of the main reasons for absenteeism from site. It was also stated that accurate and timely data can improve productivity. Ease of access was seen to be an important factor but other factors also need to be considered while trying to maintain ease of access. These factors include environmental concerns, which trades are present, where the access points are and how to manage the schedule within these constraints. Procurement plans to manage resources also showed to have an influence on productivity and an MPP should be implemented to save time and reduce some risks.

4.2.4 Summary of factors influencing labour productivity

This section discussed three main categories of factors that influence productivity. The three categories were identified from the *productivity improvement system* in Figure 4.2. Therefore, it can be said that the micro environment of productivity was discussed in this section. The following section will investigate an element from the macro productivity environment and look into the labour policies and legislation.

4.3 Labour policies and legislation

In order to understand to what measures the employer can go to improve productivity it is necessary to investigate what legislations and policies regulate these actions. In terms of section 30 of the Basic Conditions of Employment Act (BCEA) 1997 it is required of the employer to have a summary document that highlights the most important aspects of the act (The South African Department of Labour, 2004). This summary covers aspects such as working time, leave, remuneration and termination of employment. These aspects will now be discussed in order to comprehend to what measures labourers can be pushed.

4.3.1 Working time

The regular times the BCEA (2004) prescribes a worker to work are limited to 45 hours a week and limited to a maximum of 8 or 9 hours depending on the days worked in a week. Overtime may be granted but not required and should not lead to more than 12 hour work days (The South African Department of Labour, 2004). Overtime may not exceed 15 hours a week and can only be maintained for a period of 2 months every 12 months. Averaging of hours worked can be done with agreement of the employer and the employee. For averaged periods the hours worked may not exceed 45 hours per week and overtime may not exceed an average of 5 hours per week (The South African Department of Labour, 2004).

Meal intervals are prescribed and comprise of a 60 minute break after 5 hours of work. The meal break may be reduced on agreement to 30 minutes and the break may be rejected if the employee works less than six hours a day. Daily rest periods should include a 12 hours consecutive period. Each week should also include a consecutive 36 hour break which should, unless otherwise agreed upon, include Sundays (The South African Department of Labour, 2004). Employees working at night times should be informed about health and safety hazards and the right to undergo a medical examination. Public holidays are regarded as the same as Sundays; however, pay is received even if no work is done (The South African Department of Labour, 2004).

The employer and the construction managers should be aware of these regulations and time limits when they are trying to catch up with time lost in the schedule. It is especially important to take care to not overwork the labourers because not only can it exceed legal limits, but as section 4.2 showed, productivity can decrease if work hours are increased. According to Iwasaki, Takahashi and Nakata (2006) injuries are more likely to occur when labourers are overworked and accidents occurring in non-legal hours could cause the employer to pay large compensation fees.

4.3.2 Leave

Annual leave must be granted to employees and is calculated at 21 consecutive days (The South African Department of Labour, 2004). This can however, by agreement, be changed to one day leave for every 17 days worked or one hour for every 17 hours worked (The South African Department of Labour, 2004). Sick leave is calculated to be up to 6 weeks in a period of 36 months. Normally the employee is entitled to one day sick leave every 26 days worked (The South African Department of Labour, 2004). Maternity leave consists of a four month consecutive break from work. During pregnancy the employee may not perform hazardous work that could influence her or the child (The South African Department of Labour, 2004). The employee is also granted three days paid leave with regards to family responsibility. This could include sickness, death or birth of specified relatives.

If the foreman, or the person responsible for analysing the labour hours, analyses the amount of days a worker was absent, these legal leave days should be noted. However, with a good procurement plan the foreman should try to keep absenteeism low during crucial periods in the project. If activities are on the critical path of the project, the foreman should make sure that he/she has enough labourers to execute the job on schedule.

4.3.3 Remuneration

Details about remuneration should be given to all employees and the employer needs to have personal details of the employee regarding different payment aspects (The South African Department of Labour, 2004). The BCEA (2004) prescribes that compensation for overtime work should be 1.5 times the normal wage. If this agreement does not stand, the employee may agree to receive paid time off. If work is done on Sundays, the wage received should be two times the wage for normal working hours. If, however, regular work is done on Sundays, only 1.5 times the normal wage should be given. Public holidays are regarded the same as Sundays and work on these days should be remunerated with double the wage of normal working hours.

The remuneration totals should be made clear to workers to avoid disappointment. According to Bell (1985), if expectations aren't realised disappointment follows in the form of dissatisfaction which is a subjective response to the anticipated rewards. The psychological results of disappointment vary greatly among individuals. Some workers recover quickly but others may remain frustrated and mire in blame for a long period or even become depressed (Ma, 2012). This has a great effect on the motivation of the worker and influences the productivity of the worker (Ma, 2012).

4.3.4 Termination of employment

Before an employee's employment can be terminated, notice has to be given (The South African Department of Labour, 2004). The notification of termination is normally four weeks in advance if the employer was employed for longer than a year but reduces according to the period the employee was employed (The South African Department of Labour, 2004). Two weeks' notice needs to be given if the employee was employed for between six months to a year. Only one week notice is needed if the employee was employed for less than six months.

In the case of temporary workers on site, the last sentence of the previous paragraph is important. The fact that workers can give short notice of resignation is a high risk to the foremen who need to manage his or her crew's productivity and build-up. It is also important that the foreman who has a high turnover rate look at the elements in section 4.2.2.6 to reduce the turnover of crewmembers.

4.3.5 Summary of labour policies and legislation

The labour policies and legislation proves to be a factor that should not be neglected when trying to optimise the productivity of labourers on site. After this discussion the legislation can be seen as another variable that should also be integrated into the *productivity improvement system* in Figure 4.2.

4.4 Conclusion

General productivity in a construction context was described in this chapter and various models were discussed that provided an explanation of how productivity is defined. An in-depth discussion on ways to measure productivity was given, that is informative but can also be used as a guideline for implementation of the techniques. This chapter also discussed various factors that influence productivity in construction and were grouped into categories identified by a *productivity improvement system*. Productivity was seen to have a micro and macro environment and an important macro factor, legislation, was investigated. The investigation of productivity in construction was, therefore, comprehensive and provides an understanding on which the improvements of productivity can be based. The next chapter will utilise this understanding of productivity and identify restrictions in the *productivity improvement system*.

CHAPTER 5

Identifying factors restricting the improvement of productivity

In the previous chapter we investigated the factors influencing productivity. These factors were identified in categories shown in Figure 4.2 which also shows the *productivity improvement system*. This chapter investigates the *productivity improvement system* in order to identify areas within this system that can be improved so that technological solutions could be identified in Chapter 6. A number of other factors that also prohibit the improvement of productivity are also discussed. This chapter will also provide information to be used in a discussion in Chapter 8 regarding the following research questions:

1.) Which aspects of labour productivity can be improved?
2.) Can technology be used to improve a problem solving cycle of construction?

5.1 Identification of improvable areas within the productivity improvement system

The problem of low productivity level of labourers, as described in Chapter 4, is influenced by many factors. As seen in Figure 4.2 in section 4.2 of the previous chapter, a *productivity improvement system* is used to identify problematic areas of construction projects. Similarly, this system forms the basis within which problematic areas are identified in this chapter. The sequence of the discussion will take on the sequence identified in Figure 4.2. The discussion will include inputs to the system, factors influencing productivity, measurement of productivity, comparing actual versus estimate and lastly feedback and control.

5.1.1 Input to the system

Dozzi & AbouRizk (1993) identified that the *productivity improvement system* makes use of inputs which comprises of materials, personnel, management and equipment. Given the findings in the previous chapters technology can be seen as an additional input that is needed to improve productivity. However, the feasibility of these technological investments needs to be verified. The technological solutions to the labour productivity area of concern, acting as additional inputs into the construction project system, will be identified and discussed in section 6.1.

5.1.2 Factors influencing productivity

The factors influencing productivity were discussed in section 4.2 and are summarised in Table 5.1. The table is structured in the same sequence with which the problems were identified in section 4.2.

Table 5.1 - Summary of factors influencing productivity.

Management Practices
Planning - Work schedule distribution (Crowding) - Phase planning (Sequence of events) - Reduced rework and design change (Method used) - Specific trades locations (Logistics and Crowding) - Availability of materials (Locating and Logistics)
Data collection - Timely data (Real-time analysis) - Progress data (What the project looks like) - Legal data (Position of resources, Progress, Activities) - Track productivity (Whereabouts of resources)
Control - Security (Restricted areas, Theft) - Situation awareness (What is happening on site) - Rework management (Why does rework occur)
Scheduling - Stop-and-Go (Why stop and go occurs) - Approval of work (Time loss after completion of tasks) - Ripple effect (Mitigation of impact) - Multiple shifts (What happens to different trades while using multiple shifts) - Concurrent operations (Actions not accounted for in the schedule) - Overtime (Effects of overtime)
Procurement - Stacking of trades - Improved team communication - Late crew build-up - Size of crew
Labour efficiency
Individual - Attitude and personality - Safety conscious and healthy - Interruptions and 'unlearning curve' - Method inputs from labourers - Education/Training
Safety - Restricted or hazardous areas
Motivation - Minimal control mechanisms - Accountability increase - Additional authority - Performance reports - New and more difficult tasks - Specific tasks assignment
Environment - Basic needs - Temperature and humidity measure - Noise - Organised workspace
Physical limitations - Potential to perform - Nutrition
Discipline - Absenteeism - Turnover
Material and Tool Timeliness
Handling - Tools need and location - Material need - Communication
Site Layout - Jobsite planning
Procurement - Material procurement planning
Legislation - Working hours - Leave - Remuneration

These factors identified in Table 5.1 and discussed in section 4.2 are factors that have a high probability of being present in many construction projects. The degree to which they influence the project can differ from project to project. For this reason these factors, together with a relative weight of importance, should be considered when trying to improve the productivity on site and will be incorporated in the selection of solution alternatives in Chapter 6.

5.1.3 Measuring productivity

Measuring productivity is another element in the *productivity improvement system* that can be improved. Dozzi and AbouRizk (1993) described many ways in which productivity can be estimated and measured. These methods and associated problematic areas were discussed in Appendix E and the problematic areas of the measuring techniques are outlined in Table 5.2.

Table 5.2 - Summary of problematic areas with productivity measurement techniques.

Productivity measuring techniques
Field rating Fail to identify sources of problems Foreman and supervisors are always regarded as working Observations are dependent on the observer's time and place Junior and senior supervisors have different amount of crew members to supervise (added 10%)
Work Sampling Observations are dependent on the observer's time and place Observe and analyse data with calculations afterwards Large number of observations needed Indirect measure of productivity due to classifications Lack to identify the cause of inhibitors of productivity
Five minute rating Observations are dependent on the observer's time and place Represents only a short time of the activity Lack to identify the cause of inhibitors of productivity
Field surveys Data based on estimates of the foreman Timely process to analyse data
Method productivity delay model Difficulty in timing consecutive cycles of work Difficulty in timing cycle and specific delays at once
Charting techniques Many cycles need to be observed Simultaneous timing of all the trades is hard
Simulation modelling Lack of interpreting the changing environment

If decisions were to be made by management on a project to project basis (to be discussed in greater detail in section 7.1.1), the method of measuring productivity has the potential to change with each new project. Given that the problematic areas of productivity measurement are dependent on the technique used, the problematic areas can differ for each project. For this reason, when proposing technological solutions and evaluating its suitability, the evaluation model has to be versatile enough to be able to handle different problematic areas for each project.

5.1.4 Comparing estimated to actual productivity

The next element in the *productivity improvement system* is comparing the estimated productivity to the actual productivity. The quality of the comparison between the estimated and actual productivity figures rely heavily on the amount and the accuracy of the data used for the calculation (van Ark, 1996). The expression of the estimated productivity should make it clearly how it was estimated and what units of measure were used (van Ark, 1996). If the estimated productivity was calculated based on the industry standards of average rates, the actual measure should have calculations and answers that are comparable to the standards of average rates. For this reason, similar methods should be used in both calculations. If more detailed actual productivity measurements can be produced, the company should adjust the detail of estimated productivity measurements.(van Ark, 1996).

Given that this research project identifies areas where technology can improve the problematic areas, the comparison could be assisted by technology by providing more reliable, accurate and comprehensive data. Technology could also improve the comparison by employing automatic analysis through the use of software.

5.1.5 Feedback

Giving feedback is an important part of the productivity improvement process. This is where, given the appropriate layout and understanding, the workforce can be made aware of areas that can potentially be improved. However, for feedback to result in key improvements, the feedback information must be relevant, communicable and easily understood by the receivers, viz. the work force (Dozzi & AbouRizk, 1993). Furthermore, motivation is stimulated by feedback and rewards, allowing this element of the *productivity improvement system* to facilitate the recognition of high achievers with regards to productivity (Lim & Alum, 1995).

Therefore, if technology can be used to produce more data and analyse the data so that it can be used for better feedback, technology can improve motivation and hence productivity.

5.2 Factors prohibiting productivity improvement of the labour workforce

In a publication of Bardenhorst (1985) , three main categories are identified to group factors which prohibit the improvement of productivity of labourers in South Africa. The three categories were: the individual as part of the workforce, training and lastly management (Bardenhorst, 1985).

5.2.1 The individual as part of the workforce

The individual himself can be seen as a restricting factor for productivity improvements. Bardenhorst (1985) is of meaning that 12% of the identified factors that prohibit productivity improvement were related to the individual labourer himself. Important individual factors included the focus on correct recruitment and selection and also the individual's willingness to be trained. The training of individuals is influenced by whether the individual participates and contributes his or her thoughts during training. Implementing and practicing the newly acquired skills are also essential for the training to be effective.

As far as recruiting and selection is concerned, it is important to give the labourers the correct perception of the work environment and what will be expected of him or her. If expectations are not realised, disappointment follows in the form of dissatisfaction—which is a subjective response to the anticipated rewards (Bell, 1985). Similar but different to regret, where focus is on the personal decisions made, disappointment is where the individual focuses on the outcome itself (Bell, 1985).

To improve these prohibiting factors the scope of work and the work environment should be clearly defined (Bardenhorst, 1985). An integrated training program that is specific and that includes induction and skills training should be implemented (Bardenhorst, 1985). The forming of productivity groups can help to set targets that are measurable so that, in turn, management can give feedback that is measurable and specific (Bardenhorst, 1985).

5.2.2 Training of the workforce

Training of the workforce plays a significant role in the way workforce strives toward productivity improvement. It was found that 38% of the factors prohibiting productivity improvement related to training of the workforce (Bardenhorst, 1985). Major elements of training were found to be the quality of the instructors, the training program and the method of training. The control of the training officer, as well as the selection of the trainees, were also identified as significant factors influencing the effectiveness of the training programs, and the training's effect on the workforce's productivity improvements (Bardenhorst, 1985).

Improvement of these factors can be achieved if foremen provide guidance and help with the selection of the appropriate workers for training (Bardenhorst, 1985). The training quality is highly dependent on the instructors and the best qualified and appropriate instructors should, therefore, be assigned for the work. Bardenhorst (1985) also stated that training programs must be developed in line with the career path so that continuity can be created and so that the last principle of motivation described in section 4.2.2.3 is satisfied. In addition, formal training must be supplemented with site experience (Bardenhorst, 1985).

5.2.3 Management of workforce

The area of management was identified by Bardenhorst (1985) as the category with the largest number of factors prohibiting productivity improvements. Research showed that 50% of these factors related to management, including the lack of management training of line managers such as foremen. The implementation of a structured programme to develop foremen could reduce the effect of this inhibiting factor (Bardenhorst, 1985). Development of human capital should be treated as important as performance appraisal. Focus should be placed on other inhibiting factors such as neglecting to identify the specialities of the individuals in the workforce. If the specialities are correctly identified workers can be utilise them more appropriately and productivity will increase. Clear communication, especially down to the line management, could help to identify and acknowledge workers with potential in specific areas.

The lack of managing overtime also proved to have a major influence on productivity improvement. Management should also focus to manage the de-motivators that influence the morale of the individuals and rather promote actions and attitudes that show full commitment and support. This can be shown by providing a safe and healthy work environment and basic sanitation (Bardenhorst, 1985). Bardenhorst (1985) also emphasised the importance of measuring the productivity of the workforce to improve productivity. This is also stated as an element in the *productivity improvement system* in Figure 4.2 in the previous chapter and can be seen as a tool to identify shortcomings in terms of productivity.

The individual, training and management of workforce are however not the only factors that influence productivity on the construction site. These areas are important because, if improvements are needed, these are the areas that need to be eliminated so that productivity improvement can be executed without inhibitors. It is also clear from the findings of Bardenhorst (1985) that the area with the highest potential for change is the management of the workforce.

According to van der Merwe (1985) management, and more specifically line management, are the only parties that can drastically influence the quality of work and improve productivity. However Van der Merwe (1985) also states that Team Performance Questionnaire (TPQ) facilitators can assist the management and be catalysts to the improvement of productivity.

5.3 Conclusion

The different areas of the *productivity improvement system* were investigated to identify areas that could be improved on. Whilst identifying improvable areas with the improvement process, problems with the inputs to the system could not be identified. The reason for this was because technology will be proposed as the possible solution to the problematic areas and will be another input to the system. The technology will however need to be evaluated to determine its feasibility to address the problem areas and could therefore not be included as a needed input to the system.

After the lengthy discussion in Chapter 4 about the factors influencing productivity, a summary of these factors is provided in this chapter. These factors proved to be important because the likelihood that these factors are present on different projects is high. However, as identified earlier in this thesis, projects differ and the degree to which these factors influence projects can differ. For this reason it was identified in this chapter that a weight should be linked to these factors, to correctly determine its project specific importance. This will have to be incorporated in the decision making process that will be discussed in the next chapter.

Many restrictions and difficulties were identified with the various productivity measuring methods. However it was not the vast amount of improvable areas identified that was the main realisation. It was the fact that the different restrictions and problems are method specific and, therefore, project restrictions in terms of productivity measurement will be determined by the method used. It was, therefore, deduced that in order to evaluate the feasibility of a technological solution, for the measurement of productivity on a project, the evaluation model has to be flexible enough to be able to be used with different sets of restrictions and problems.

The amount and quality of data captured plays a significant role in the improvement of comparing the estimated and actual productivity measurements. If technology is proposed to improve this area of the *productivity improvement system*, it should be able to assist in providing more and higher quality of productivity data. Technology could further improve this area if the technology could do the comparison of actual versus estimated productivity automatically in a way that is understandable. If the feedback of productivity is understandable and can contribute to the motivation of the workforce, it could further improve productivity.

Other productivity improvement inhibitors that were identified in this chapter include the individual, training and management. The individual was seen to be related to 12% of the productivity inhibiting factors. The willingness to be trained, participation and contributions as well as the reaction of the worker to the work environment are seen to be the important productivity improvement inhibitors related to the individual. The training of the workforce was also seen as a major productivity improvement inhibiting factor. 38% of the factors inhibiting the improvement of productivity are related to training of the workforce. Important areas of training are the qualifications of the instructors, the method of training and the selection of the right trainees. Furthermore it was seen in this chapter that 50% of productivity improvement inhibiting factors were related to management. One of the reasons why management inhibits productivity improvement is because the line managers are not trained appropriately. Bardenhorst (1985) stated that development of people should be as important as performance appraisal. The lack of managing overtime and de-motivators are two factors, according to Bardenhorst (1985) that stand out as productivity improvement inhibitors. Bardenhorst (1985) further highlighted that failing to measure productivity is another inhibitor that is overlooked in terms of productivity improvement.

However, besides all the productivity inhibitors identified in this chapter Jorgenson and Yu (2010) have proved that policies that focused on increased technology usage have improved the growth of total factor productivity and labour quality. Furthermore, van Ark and de Haan (2000) stated that the low productivity levels can be attributed to the slow acceptance of technology in businesses. It is for this reason that the next chapter will investigate technology and the development thereof in construction.

CHAPTER 6

Identification of possible technological solutions

Following on Chapter 5, where areas of improvement were identified, this chapter presents the process of identification and evaluation of technological solution alternatives. Some technologies are viewed as possible solutions to the labour productivity problems experienced by contractors in the South African construction industry. The process that was used to identify technologies is explained.

This chapter will also provide information to be used in a discussion in Chapter 8 regarding the following research question:

1.) What technology can be used to address this area of concern?

6.1 Identification of technological solutions through learning from other industries

From the discussion in Chapter 4 regarding the factors influencing labour productivity it can be seen that labour productivity relies heavily on the behaviour of the labourer and how he or she reacts to the environment in which they work. The challenge faced when trying to improve labour productivity is therefore to introduce solutions that will help to utilize the full potential of each labourer when he or she arrives for work on the site. The solutions must, therefore, influence the behaviour of the workers and direct their potential to complete tasks more efficiently.

Monitoring technology has succeeded in various other spheres to influence and almost dictate behaviour of individuals and groups. Examples of such spheres are sports such as soccer, rugby and Australian football. Traffic regulation on roads is another area in which similar effects were seen when monitoring technology was used to control drivers' behaviour (Venter, Opperman and Opperman, 2011; Barros, Misata, Menezes, Figueroa, Moura, Cunha, Anido, Leite, 2007; Edgecomba & Norton, 2006; Stradling, Martin, Campbell, 2005).

Given the rising competition in sport, technologies were implemented to assist team managers and fitness staff to improve the way in which the players were trained and how they performed during matches (Waldron, Twist, Highton, Worsfold, Daniels, 2011). Technologies that are currently used to optimise training and games can be divided in two categories. The first category is manual and automatic visual analysis image processing and the second is wireless tracking.

Manual image processing requires the analyser to watch videos to derive data from the images on the screen regarding the movement of the players relative to the field markings. Visual analysis can also be done automatically with software packages that analyse the movement of objects by interpreting the contrast in pixel colours on the screen.

Wireless tracking of players is done by attaching a transmitter to the players that sends signals to receivers. These receivers send the data to software packages to interpret the movements of the players.

These two categories of technologies will now be considered in further detail to see how it could be used for labourers on a construction site.

6.1.1 Visual analysis and image processing technology

Visual estimation works on the principle of image segmentation and tracking. Image segmentation is where a video is analysed frame by frame and the distances and speeds of the player's movements are tracked based on the difference of the consecutive frames (Barros, et al., 2007). This calculation can be done due to the constant frame rate of the camera and the known parameters of the playing field (Barros, et al., 2007). Automatic estimation works with complex software that recognises different objects given the pixel arrangements of the frames (Figueroa, Leite, Barros, 2006). Players can thus be tracked automatically by a computer aided method (Figueroa, et al., 2006).

Video analysis technology has also been used in sports arenas where fans are filmed and is predicted to be utilized in shopping malls and airports (Gregory, 2013). In this instance the behaviour of those monitored is not influenced by the monitoring technology because most are unaware of the cameras. The footage is used and analysed by software that was developed in the New York University Movement Lab (NYU Movement, 2013). The video and software combine to determine the activities of, or reaction to specific occurrences in the spectators' immediate environment (Gregory, 2013). This analysis has improved stadium dynamics and has helped team marketing agents to create a more entertaining atmosphere for different spectators (Gregory, 2013).

The development of various 2D resource mapping methods has given the field of video tracking various alternative base methods to choose from. Examples of these different 2D mapping techniques are contour-based tracking, kernel-based tracking and point-based tracking (Park, Makhmalbaf, Brilkis, 2011). An investigation of these methods, specifically with regards to the implementation thereof on construction sites, showed that for a given criteria, kernel-based tracking provides the best 2D tracking reliability and accuracy (Park, et al., 2011). The advantages of such a mapping system will be discussed in the following sections.

6.1.1.1 Technical advantages

Video tracking only requires the installation of digital video recorders and an analysing system comprising of computers with specific software (Park, et al., 2011). Thus no tags need to be placed on the resources in order to recognise them (Park, et al., 2011). Developments in these fields are being researched and automated visual tracking is regarded as one of the most anticipated technologies that will transform construction (Park, et al., 2011). 2D tracking of resources, for example kernel-based tracking, provides a good base for 3D mapping (Park, et al., 2011). Teizer, Caldas and Haas (2007) concluded that 3D detection tracking can give accurate data about the position, direction and speed of the resources detected (Teizer, et al., 2007).

6.1.1.2 Implementation advantages

In a construction context, the visual tracking of resources such as materials, labourers and equipment provides the video analyser with data to monitor processes, deduce activity sequences and determine productivity measurements (Teizer, et al., 2007). Having data that is real-time can be used for safety purposes, especially when large moving equipment is in close proximity to labourers (Teizer, et al., 2007).

6.1.2 Wireless tracking technology

GPS tracking of a player works on the principle that signals are transmitted from a device, attached to the player, to satellites orbiting earth and that the position of the attached device is calculated. Therefore if the player moves, the device moves and the speed, distance and exact coordinates of the player can be analysed (GPSports, 2012). Top range sports watches also incorporate the GPS functionality to track speed, distance and coordinates of its users (Garmin Ltd., 2013) (Polar, 2013), (Suunto, 2013).

CAIROS Technologies Company has developed a system to track soccer players as well as the ball by using two cameras and local receivers around the soccer field that captures the frequencies of the transmitters (CAIROS Technologies AG, 2004). This is similar to the GPS tracking mentioned in the paragraph above, but the receiver of the data is localised and does not make use of satellites. Another difference is that the unit that the players have to wear are much smaller. Figure 6.1 shows the GPS transmitter (74mmx42mmx16mm) used for rugby players on the left and the CAIROS transmitter (22mx22mmx5mm) on the right.

According to Jiang, Jang and Skibniewski (2012) wireless tracking used in construction includes technology such as GPS, Wi-Fi, radio frequency identification (RFID), Bluetooth, ZigBee and Ultra wideband (UWB). The findings of Jaing, *et al.* (2012) showed that UWB technology is the most suited wireless technology to use for construction sites. This conclusion is based on the input of various construction professionals who rated the alternative methods of wireless tracking, given a specific set of criteria for selecting wireless technology. The ratings were made, given a specific scenario where the technology had to be used to track resources on a site that has many different buildings and obstructions as well as open spaces (Jaing, et al., 2012). Figure 6.2 shows how the UWB transmitters have been used on construction sites on various resources such as labourers, material and equipment

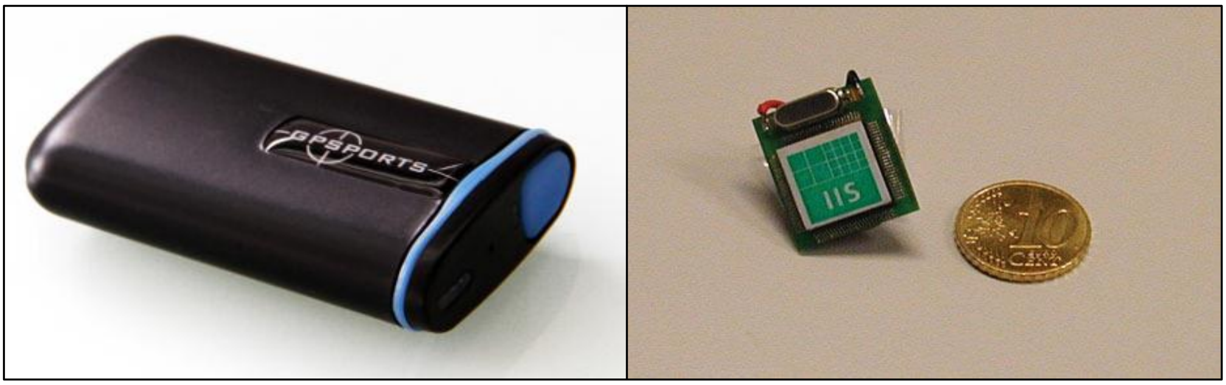

Figure 6.1 - GPS unit used for rugby (left) and a transmitter developed by CAIROS technologies (right) (GPSports, 2012) (CAIROS Technologies AG, 2004).

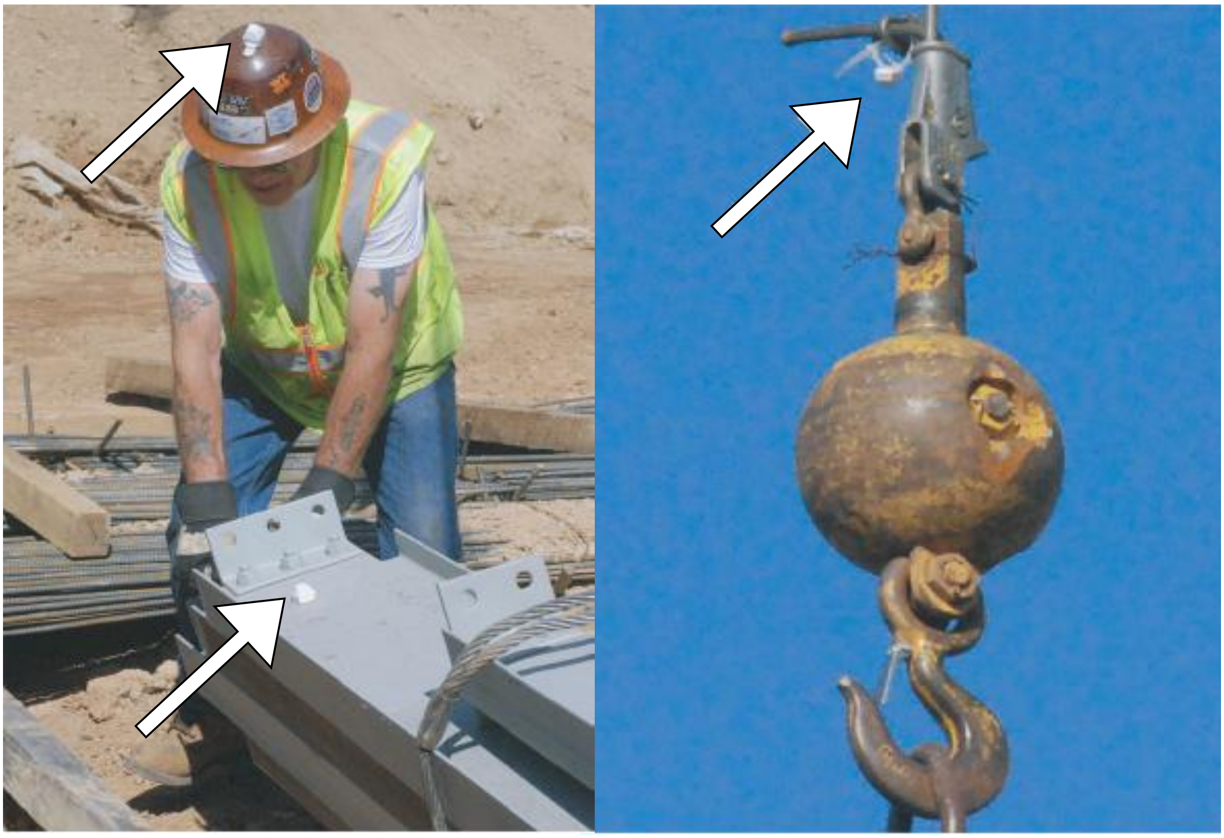

Figure 6.2 - UWB transmitters on labourer's hardhat, end of steel beam and on crane hook (Jaing, *et al.*, 2012).

The benefits of UWB are described by Jaing, Skibniewski, Yuan and Sun (2010) in their publication where they analysed the tracking of resources such as labourers, materials and equipment. They found that UWB had the following benefits:

6.1.2.1 Technical advantages

The UWB system has high data rates that work on a broad band of frequencies. This enables the tags that are placed on the resources to be picked up even through thick obstacles and even underground (Jiang, et al., 2010). The tags are battery operated and can last for a year which has great benefits in terms of maintenance (Jiang, et al., 2010). The tags only weigh 12 grams and can be placed on crane hooks, equipment and labourers' hard hats (Jiang, et al., 2010). The large frequency width allows the data to be immune to disruptions from other radio signals or even obstacles and buildings. The UWB system can locate tags in 2D and in 3D which proves valuable when resources work on different levels of buildings (Jiang, et al., 2010). The tags do not need calibration and the receiver setup can be kept in the same way during the life of the project, which saves time (Jiang, et al., 2010).

6.1.2.2 Implementation advantages

Besides the technical advantages of UWB, implementation of this technology provides additional benefits (Jiang, et al., 2010). These benefits include the ability to assess resource status, determine work task performance and receive real time feedback of position of resources. Resources such as labour, material and equipment can all be tracked in real time, giving the analyser the ability to make real-time decisions (Jiang, et al., 2010). Teizer, Venugopal and Walia (2008) proved that UWB can facilitate site productivity analysis and provide control of work task schedules. This is stated to ensure return on investment and increase overall construction performance (Teizer, et al., 2008). According to Giretti, Carbonari, Naticchia and De Grassi (2009), good safety management requires continuous analysis of the workers' behaviour and the ability to give timely warning signals in possible dangerous situations. Given the ability to provide data in real-time, UWB technology, together with a small tag which is able to vibrate, signal and flash, can effectively be used as an automated safety management tool (Giretti, et al., 2009).

6.1.3 Summary of identification through learning from other industries

The most important aspect taken from these different application areas is that the technology managed to change the behaviour of the monitored parties. Technology that influence behaviour could improve labour productivity since Chapter 4 showed evidence that labour productivity is highly dependent on the labourers' behaviour.

6.2 Conclusion

In this chapter technological solutions were identified based on the core problems with labour productivity. The concern with low productivity of labourers was dissected in detail in previous chapters and two realisations were identified and were used to research similar concerns in other industries. Two groups of technologies were identified as potential solutions that could influence worker behaviour to complete tasks more efficiently. The findings of researching other industries showed that other industries can assist the construction industry with the identification of technological solutions. The two technologies that were investigated were 1) wireless tracking and 2) visual analysis and image processing.

CHAPTER 7

Evaluation of possible technological solutions

In this chapter the decision making process is discussed and reference is made to the way in which different models can be utilised to make decisions regarding change in companies. The technological solutions that a company will identify have to be evaluated to see whether they are suitable for use in construction and if they will produce a net benefit. The criteria for selecting technology will therefore also be discussed. After the criteria have been selected a method of decision making is explained. This method makes use of a model which is able to utilize the criteria, business strategy and individual perceptions of different stakeholders within the decision-making process.

This chapter will also provide information to be used in a discussion in Chapter 8 regarding the following research question:

1.) How will the effects of the technology be quantified in terms of cost versus benefit?

7.1 Decision making in construction

Literature states that there are many models used by the corporate environment to solve business problems (Grunig & Kuhn, 2005; Noorderhaven, 1995; Proctor, 2010). Many of these models incorporate a process to improve current areas of concern. This process involves identifying alternatives to choose form, a procedure for making decisions and an action plan based on the decision made. Given that this research investigates technology investments the term *alternative* will refer to a technological system such as a UWB wireless tracking system or a visual analysis and image processing system.

The group of alternatives that can be chosen from in a Multi Criteria Decision Model (MCDM) are finite and can range from two to hundreds (Triantaphyllou, et al., 1998). One alternative that should always be incorporated in the group of possible solution alternatives is the “do-nothing” alternative. This alternative simulates the investment in nothing. When this alternative is included, the Decision Maker (DM) can determine whether to investment in an alternative or not invest at all.

In this section different approaches of decision making will be discussed and differentiation is made between the detail of decision making and the different levels of decision making.

7.1.1 Decision making approaches

Noorderhaven (1995) listed four conceptual models of organizational decision making. These four processes are the synoptical planning models, disjointed incrementalism, logical incrementalism and the interpretive approach. These models will now be investigated to see how these models relate to decision making used by the investigated construction companies in South Africa.

7.1.1.1 Synoptical planning models

Synoptical planning models are structured models that aim at providing guidelines to practical management and decision making (Noorderhaven, 1995). The guidelines are formulated based on all the procedures and practices of the business in a single procedure (Noorderhaven, 1995). This model creates room for strategies to be changed and is ideally implemented annually when management reconsiders the approach for the business year (Noorderhaven, 1995).

There are two variants of the synoptical planning models and are called the design school and the strategic planning school.

The design school is characterised by an informal, top-down approach. This means that the CEO is regarded as the strategist and the input of the lower management is recognised but lower management's role is to receive the strategy decided upon by the CEO (Noorderhaven, 1995). The strategy is regarded as informal due to the fact that the CEO has broken the strategy down into understandable units that can be understood by the lower managers that have to implement this strategy. One major drawback of this decision making model is that it relies on communication from the CEO, which is time bound, and therefore hampers the ability to learn progressively between communications.

The other variant of the synoptical planning models, the strategic planning school, is a much more formalised approach. The approach is often depicted with flow charts and diagrams that refer to the methodologies of a computer program. This formal approach stems from the belief of long term controllability of companies and that a formalised and archived strategy provides a reference for continual redirection (Noorderhaven, 1995). These strategies are also grounded on the belief to be able to predict future events and movements of their business market, thus their strategy is formulated from rational deduction of existing data.

7.1.1.2 Disjointed incrementalism

The prescriptive nature of the synoptical planning models differs from the descriptive nature of the disjointed incrementalism approach. In this approach managers play a less influential role in the redefining of the company strategy. They are expected to only manage changes in the existing situation. Consequently the business strategy hardly ever changes and if it does, it is small, therefore incremental. The approach is categorised as disjointed in the sense that the decisions made are incoherent and are focused on current issues. The fact that no future predictions are made, with regards to events or changes in their business market, or that aims are hardly ever set for longer than a year in advance, creates an environment of disjointed decisions-making.

7.1.1.3 Logical incrementalism

The logical incrementalism approach is similar to the disjointed approach in that it is also a fragmented process. However two other characteristics of this approach are that it is intuitive and revolutionary. It is intuitive, because in many instances the DM relies on his or her own intuition. This is sometimes the only means to make decisions if there is no common denominator by which the advantages and disadvantages can be evaluated. It is a revolutionary approach due to the fact that a decision is made with no clear rational procedure and there is an absence of information to rationalise the decision.

At this stage the logical and disjointed incrementalism appear the same; however, with logical incrementalism there is an underlying long-term strategy. This strategy is not the primary focus, because the individual manager argues that in order to achieve the long term goal he or she needs to change strategy incrementally. There is thus a logical component of decision making where the deviation from an overpowering strategy is seen to be more suitable. Logical incrementalism is also an effective way of learning in an organisational context. Changes are incremental and thus smaller, this allows the learning curve to be concentrated over a shorter period. Lower level managers are in charge of making these smaller decisions to eventually reach the overall strategy and therefore a bottom-up orientation is found. This allows for timely and accurate feedback that can be utilized for improvement.

7.1.1.4 Interpretative approach

With this approach a semi closed system is a good representation of the decision making process. A group approach to decision making is used when changes are made rather than an individual approach. The changes are decided on and approved by an organisational paradigm that is formed by the general consent of the managers involved. The environmental effects and changes are therefore not interpreted by the individuals but by the group of managers. This provides a much more gradual change over time and to an extent filters individual perceptions of change.

7.1.1.5 Interpretation of decision making approaches of South Africa construction companies

After correspondence with five managers of construction companies in South Africa, it was clear that decisions about changes are made by managers (Egerton, 2013; Phenix, 2013; le Roux-Arries, 2013; Jackson, 2013; Schonrock, 2013). The companies which were included, Avenge Grinaker LTA, Group Five, Murray and Roberts and WK-Construction all have underlying strategies but emphasis is placed on the decision making of the project - and contracts managers. For this reason it can be said that neither the synoptical approach (where the CEO dictates) nor the disjointed incremental approach (where there is no prescriptive strategy) are dominant within the interviewed companies. Schonrock (2013) indicated that individual managers do research in their own capacities and change their own implementation strategy accordingly. The individual responsibility for decisions is encouraged because each construction project is different and requires non-standard interpretations for success. For this reason it could be said that a tendency towards a logical incremented approach is followed. However, Jackson (2013) stated that decisions are incremental but are made by a group of managers at project proposal stage. This gives evidence of the interpretive decision model and the existence of an organisational paradigm.

The reason for the presence of this mixture of decision models could be explained if one assumes that the group of managers involved in decision making serves as both an aide-mémoire of the underlying long term strategy and an organisational paradigm.

Proctor (2010) mentioned that the existence of computer-assisted creative problem solving made the decision making process easier and faster. Computer-assisted creative problem solving models cannot solve the problems on their own, but requires the user to provide information to the system (Proctor, 2010). Computers can, therefore, help with the logical interpretation and visualisation of decisions (Proctor, 2010). From the interviews it can be deduced that the use of computer systems as part of a decision model or procedure is not implemented in the companies interviewed. The concept of decision models will, however, be discussed in detail in section 7.3.

7.1.2 Level and detail of decision making

In section 7.1.1 approaches of decision making were identified and compared to the way in which contractors make decisions in South African construction companies. This section will discuss how decision making can differ in terms of its level and detail irrespective of the decision making strategy. The level and detail of decision making will be defined in the following subsections.

7.1.2.1 Level of decision making

According to Du Preez *et al.* (2010) a company can be seen as a system containing different processes that operate on different levels. The processes can be engineered both individually and holistically. These different levels of the business are focused on short –, mid –, and long term goals respectively and employees managing these levels have different management levels. The level of decision making, therefore, refers to the business area or level in the company at which the decision making takes place.

Bowett (2012) identified that there are three levels of decision making in companies, namely strategic -, tactical -, and operational decision making. These decisions are made by different individuals and some are in higher management positions. Figure 7.1 gives an indication of who is involved with what level of decision making within a company.

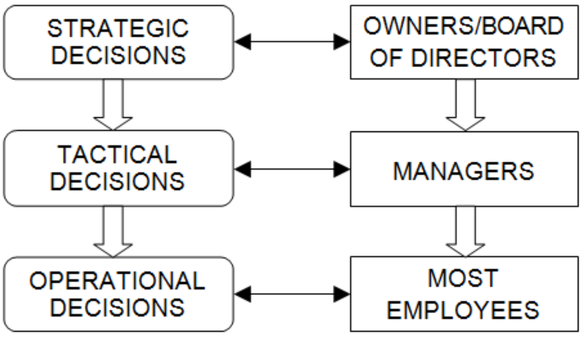

Figure 7.1 - Levels of decision making in a business (Bowett, 2012).

Strategic decisions are decisions that impact the focus of the company and are regarded as long term decisions (Management Study Guide, 2013). These decisions are made by top-level management and include the mission, vision and strategy of the company (Taylor, 2012). Strategic decisions are high impact and low volume decisions and are based on large amounts of information (Taylor, 2012). These decisions influence the company drastically and some information is kept confidential within the top management before implementation (Taylor, 2012). An example of a strategic decision is the decision on whether or not to invest in a new branch of the company.

Tactical decisions support the strategic decisions and are made by mid-level managers. These decisions focus on management and control of a company (Taylor, 2012). These decisions are repeatable decisions and have close to the same alternatives with slight changes, which make them ideal for decision management systems (Taylor, 2012). An example of a tactical decision would be to select the appropriate marketing strategy or the number of staff members for the new branch should it be decided to start one.

Operational decisions are also called administrative decisions and are made by lower management, supervisors or base level employees (Taylor, 2012). These decisions have a short term impact and are repeated on a daily or weekly basis. The outcomes, regardless of the alternative the employee chose would more or less be the same (Taylor, 2012). Although these decisions may not have a single big impact, the sum of these decisions does add up to great amounts (Taylor, 2012). It is therefore necessary that policies and a well-defined decision management system are used for these decisions (Taylor, 2012). An example would be the choice between who hands out the fliers and who prints the brochures for the new branch launch.

Large construction companies such as AVENG Grinaker LTA has experienced many structural changes in terms of the amount of managers and amount of different levels of the business (Bothma, 2012). However, the business structure in Figure 7.2 has remained relatively constant over the last ten years (Bothma, 2012). This figure shows that one company can have a number of divisions. These divisions operate in either different fields of work in construction or are geographically grouped (Aveng Grinaker-LTA, 2013). Whether they are categorised geographically or by their field of work, the divisions have projects that they operate. These projects, regardless of what type of work is performed, consist of tasks or activities that make up the project.

Based on the interviews with the respective managers of South African construction companies it was clear that decisions regarding new technologies or work methods are made at the pre-project or pre-tender phase (Jackson, 2013). The decisions are made by the project managers who have to make a decision on whether or not they are willing to take the risk of the investment (Jackson, 2013). This means that many decisions regarding new innovations are made for implementation on a specific project.

Given the above mentioned statements, it can be deduced that many decisions are made by managers on a project level and would therefore be regarded by Bowett's (2012) categories as tactical decisions.

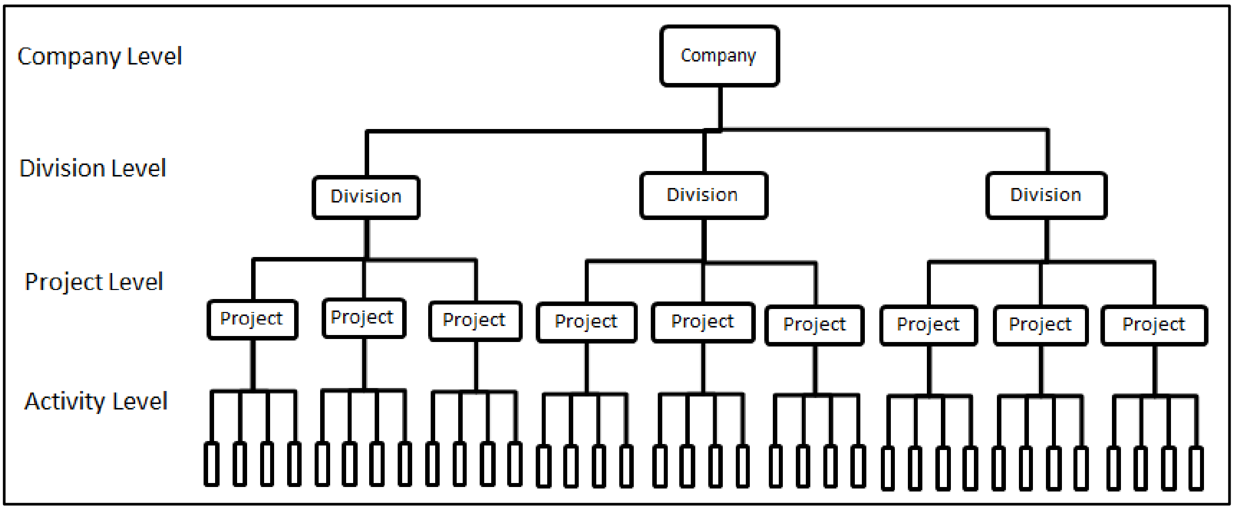

Figure 7.2-Different organisational levels within AVENG Grinaker LTA as described by Bothma (2012).

7.1.2.2 Detail of decision making

The more areas of impact are investigated when making an investment decision, the better the holistic impact determination of the investment. According to du Preez, *et al.* (2010) change can have short and long term effects, but these effects are dependent on a well-executed change cycle. The change cycle refers to the way in which the change is managed once it has been implemented. A well-executed change cycle therefore refers to a detailed estimation of the effects of the change and a sound plan to manage the changes. The detail of the evaluation refers to the amount of impacted areas that are considered when making the decision. To accurately determine the effects of change the detail of the evaluation needs to be high.

Decisions may have different timeframes within which the decision must be made. These timeframes influence the detail of the evaluation. If the decision needs to be made within a short time, a fully detailed evaluation cannot be done and the evaluation will not include a detailed analysis of all the levels that can be influenced. For this reason decision makers should be aware of the detail of decision making when they want to determine the effects of their decisions within a specific time.

7.1.2.3 Summary of the level and detail of decision making

Levels at which decisions are made in an organisation are determined by whether the outcome will impact the company on a strategic, tactical or operational level. The anticipated impact of the decision thus determines who the employees are who make that decision. The detail of decision making is influenced by the allocated time to make the decision and the accompanying uncertainty of data needed to make the decision. When decisions are made on different levels, the personnel, aim and especially the detail of making those decisions are different from another level. However, it is hard to determine the impact of a decision if a decision is made regarding something new. This is, more often than not, the case with technology investments and the decision regarding the use thereof. The high level of uncertainty in evaluations of technology is confirmed by Chou, Chou and Tzeng (2006). They also stated that technology investment decision require a more intricate decision making process to fully understand the effects of technology.

With technology investments it is not sure in which level of the organisation the effects of the investment will be present. For this reason differentiation between level and detail of technology investment decisions should be neglected and criteria should rather be identified to evaluate the feasibility of the investment (Chou, et al., 2006). These criteria should then include the details that all the different levels of decision making require. These criteria will be discussed in the section 7.2.

7.2 Criteria for evaluating technological investments

Chou et al.(2006) stated that criteria are needed to make informed technology investment decisions that incorporate the requirements of feasibility of different levels of business. For this reason we will investigate what criteria is necessary to satisfy all the feasibility requirements of all levels of management.

Traditional appraisal techniques' ability to integrate the softer benefits of technology investments have often been debated (Farbey, Land & Targett, 1993). This is due to the fact that many of these softer benefits are not easily quantifiable in financial terms (Farbey, *et al.*, 1993; Lefley & Sarkis, 1997; Irani, 2002). In addition, traditional techniques of appraisal do not consider social, political or behavioural factors (Serafeimidis & Smithson, 2000).

Chou, *et al.* (2006) did an extensive study determining which criteria should be incorporated into the model for decision making of information technology (IT) and information systems (IS). They investigated many attempts of researchers to compile a group of criteria and compiled a summary of the work of the researchers. This summary of criteria and the sources where the criteria were identified can be seen in Appendix F. These criteria listed in Appendix F can be grouped in categories such as external criteria, internal criteria, risk criteria, cost criteria and benefit criteria.

The criteria that Chou *et al.* (2006) used were tailored to information systems investments. The criteria within the benefit category were therefore aimed at measuring the performance of these systems. This research thesis has identified wireless tracking and visual analysis as two possible groups of technological alternatives for the improvement of labour productivity. For this reason the benefit criteria should be tailored to be able to determine whether the specific technological alternatives can be beneficial given the labour productivity problem at hand. The other categories of criteria remain relatively the same because they are inclined to determine what other effects the technological alternatives would have on the way the company does business.

The technological alternatives that are considered in the decision making process will be regarded as beneficial to labour productivity if these alternatives satisfy the benefit criteria. In Chapter 5 we identified the factors restricting the productivity improvement framework. These factors influencing productivity were therefore incorporated into the benefit criteria category. Figure 7.3 as well as Appendix G show how the criteria were organised in the different criteria categories and how the areas identified in Chapter 5 were incorporated in the benefit criteria category.

When using these criteria it is important to know that ratings should be given, by the decision makers, with regards to the degree to which the alternatives satisfy a given criterion. If an alternative has a negative effect on the business specifically relating a criterion, the rating given by the decision maker should be low, thus reflecting a minor degree of satisfaction. The worst negative influence on the business becomes the baseline for the degree of satisfaction and the alternatives degree of satisfaction should be rated relative to the baseline. The different categories of criteria that will be used to select the appropriate alternative will now be described.

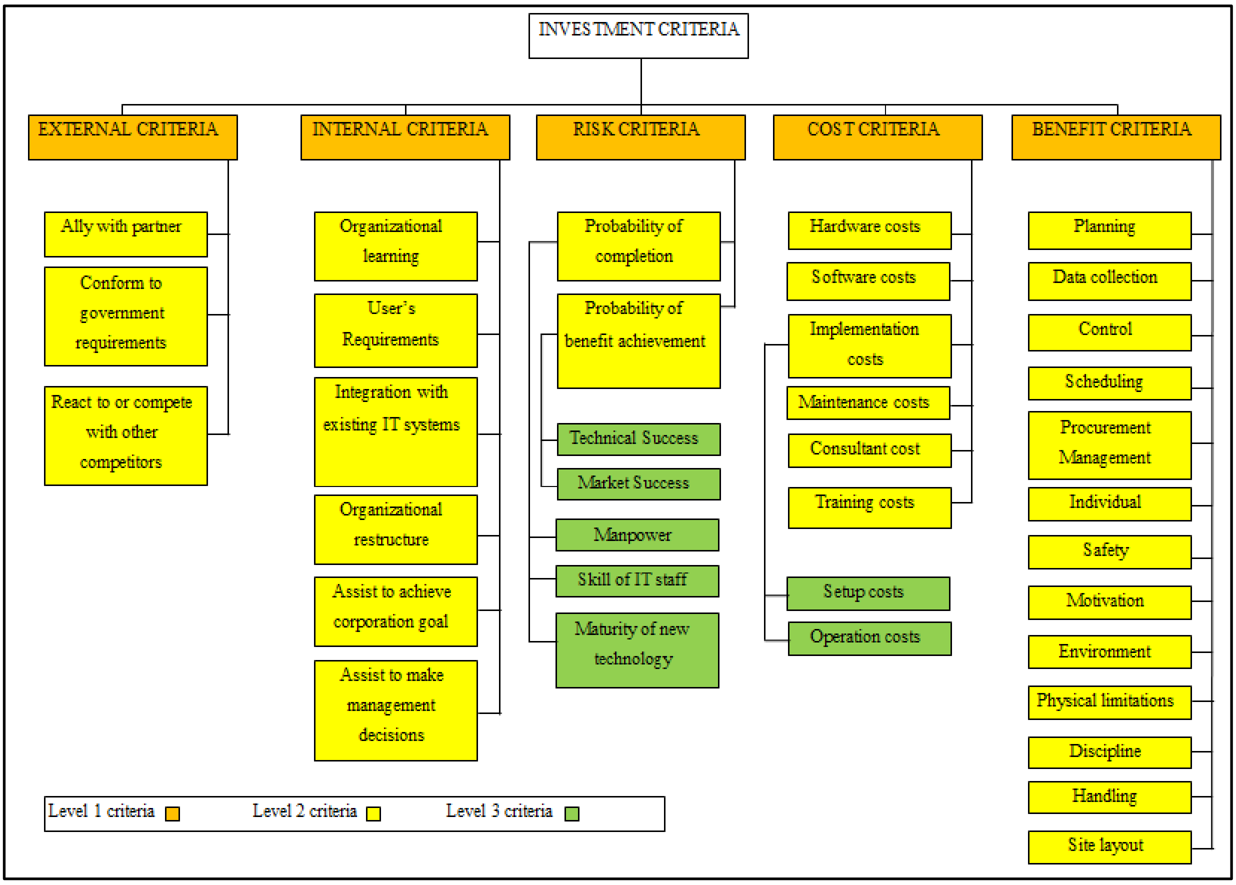

Figure 7.3 - Criteria structure for investment decisions regarding labour productivity improvement technology.

7.2.1 External criteria

The external criteria are focused on the elements outside of the company that play a role in considering an alternative for implementation in the company. This includes the industry regulating boards, government and other companies in the industry.

7.2.1.1 Partner alliances

To form an alliance with a partner means that you join resources and collaborate with another entity, whether it is another company or an individual. In section 2.2.4 collaboration and partnering have shown to be beneficial in R&D and could be beneficial in business context. This criterion is therefore incorporated in the collection of decision making criteria to evaluate whether the investment in a proposed alternative would be beneficial with regards to collaboration with partners.

7.2.1.2 Conform to government requirements

Government regulations and political considerations are incorporated into the decision making criteria to make sure that the proposed solution considers the legality of implementing such an alternative. When assessing an alternative focused on improving labour productivity, labour legislation, occupational health and safety acts and other relevant regulatory publications should be considered.

7.2.1.3 React to or compete with competitors

According to Jackson (2013) competing with competitors is an important part of the survival of a construction company and should therefore be incorporated in the decision making criteria. This criterion focuses on whether the alternative gives the company a competitive advantage in terms of service delivery. This criterion evaluates advantages that make your company better than the competitor.

7.2.2 Internal criteria

The internal criteria focus on the areas that need to be considered that are specific to a given company. These areas include, among others, compatibility with current systems, organizational restructuring and whether the alternative assists the achievement of the corporate goal. Byrd *et al.* (2006) states that strategic alignment is essential if IT investments are to support the firm's goals, objectives and activities. Byrd *et al.* (2006) also indicated that there is a synergistic coupling between strategic alignment and IT investment with firm performance. It is further stated that firms that have aligned IT and business strategies can invest in additional IT resources with some assurance that they will be leveraged substantially.

These internal criteria incorporate alignment of the current business strategy and objectives, and for this reason this collection of criteria tests the IT/IS alignment of the technology alternative with the current business strategies.

7.2.2.1 Organizational learning

This criterion forces the decision maker to consider whether the organisation will learn something from the implementation of an alternative. If an alternative is something new, the chances are good that the organisation will learn. However, if the alternative will be managed by a partnering or outsourced organisation the potential for learning within your organisation could be reduced.

7.2.2.1 User's requirements

The user's requirements is another criterion that should be incorporated into the decision making criteria. In some instances the user will require more knowledge to use the alternative or in some instances the user might require the alternative provide more functionality. This criterion, therefore, lets the DM evaluate how well the alternatives synchronise with the user's requirements. The considerations include the ease of use, the size of the implements, the accuracy of the device and the robustness for use on a construction site.

7.2.2.2 Integration with existing IT systems

The integration of the alternative into the existing IT systems is regarded by Chou *et al.* (2006) as an integral part of assessing whether or not to invest in new IT. The alternatives must, therefore, be tested for flexibility, data rate, accuracy and whether it can be used in the way it should be and still address the problem. This means that if the problem that should be solved is low labour productivity, the alternative should for example be able to assist or improve the current productivity measuring method used. Section 4.1.2 mentioned a few possible measuring methods, and the restrictions with these measuring methods are listed in Table 5.2 in section 5.1.3. These restrictions are typical tests that can be used to see how well the alternative can improve these measuring methods.

7.2.2.3 Impact of organizational restructuring

Organizational restructuring can have positive and negative influences on a company (Bothma, 2012). This criterion must therefore not measure whether or not organizational restructuring is going to take place, but what the impact of such a change will be. The DM should consider how well the alternative under question is going to affect the company in terms of organizational restructuring. If restructuring is always perceived as a negative aspect in a company, the alternative that causes the least amount of change should receive a better rating in this category. The opposite, where restructuring is perceived positive, could also be incorporated into this criterion. However, it is important to evaluate the positive impact the alternative has on the company given this criterion.

7.2.2.4 Assist to achieve corporation goal

This criterion forces the DM to consider whether the alternative under question supports the strategy or goals of the organization. AVENG Grinaker LTA is focused on providing their workers with a safe working environment, hence the slogan ”Home without harm, everyone everyday” (Aveng Grinaker-LTA, 2013). Therefore, this criterion would, among other considerations, evaluate the way in which the alternative supports a safe working environment in AVENG Grinaker LTA. According to Bacon (1992) this is the most important criterion from the survey he conducted in his research.

7.2.2.5 Assist to make management decisions

The importance of this criterion to management on different levels is dependent on which decision making approach (section 7.1.1) exists within the company. If the management decisions are being made by the project managers, this criterion would be of value to the project managers. This criterion focuses on the ability of the alternative under question to assist the DM with making management decisions. This criterion should, therefore, consider how well the alternative under question provides data to make decisions on management level. If for instance the alternative helps the project manager to determine the position of the equipment shed, based on previous site logistics tracking data, the alternative could get a positive rating for this criterion.

7.2.3 Risk criteria

This category of criteria is focused on the risks involved with making investments. According to Bacon (1992) this group of criteria is often neglected or incorporated in assumptions based on the outcomes of other criteria. Nonetheless he mentions the importance thereof by stating that where it is used by companies, it is regarded by management as the most important criteria, even exceeding the budget constraint criteria.

7.2.3.1 Probability of completion

The probability of completion of the investment project can be calculated by various considerations of which Chou *et al.* (2006) highlighted manpower, skill of IT staff and the maturity of the technology which are all key to technology investments.

7.2.3.1.1 Manpower considerations

Manpower refers to the availability of resources, especially staff to implement the alternative. This criterion urges considerations of staff availability and whether the alternative will influence the manpower of the company. If the investment in the alternative causes the firing of some workers, this criterion incorporates that as well.

7.2.3.1.2 Skill of IT staff

This criterion considers whether the current skill level of the IT staff within the company can deal with the knowledge level needed for the alternatives. The lack of enough skill can only be seen as a negative in terms of probability of completion of the task, even if the company sees the training of staff as important and good.

7.2.3.1.3 Maturity of new technology

The maturity of the technology was a criterion that Chou *et al.* (2006) proposed to be part of the decision making process for determining the probability of completion of the task. This is due to the fact that if a technology is underdeveloped it might give problems in terms of usage restrictions that are not yet picked up by other users.

Together manpower, skill of IT staff and Maturity of the technology form a unit by which the probability of task completion can be estimated.

7.2.3.2 Probability of benefit

This criterion urges the decision maker to consider what the probability is that a specific alternative will provide the benefit it states. Benefits are formulated by the sales person or the supplier of the alternative. However, research should be done with other users to verify the effectiveness of the alternative and whether it provides the stated benefits. Bacon (1992) stated that having this criterion separate from other criterion force the management to think realistically about the implementation. This facilitates growth of a thought process within the DMs.

7.2.4 Cost criteria

The cost criteria are different from the other criteria due to the fact that the highest score for cost of the alternatives implicates that the cost implication of that alternative is the lowest. Alternatives should be rated based on the costs discussed in the sections to follow.

7.2.4.1 Hardware costs

The hardware costs are compared between the alternatives and the lowest cost receives the highest score. It is important to incorporate this criterion when making technology investment decisions, because this is often the largest investment and also becomes one of the main expenses for consideration in cost benefit analysis (Jones & Beatty, 1998) (Iacovou, et al., 1995) (O'Callaghan, et al., 1992)

7.2.4.2 Software costs

The software costs can include the costs of the data analysis package and process control amongst other expenses. This cost could also be included in the cost of the hardware depending on the agreement with the sales person. If the software needs to be installed on different devices and a consultant is needed, the installation costs should be allocated to consultant costs discussed in section 7.2.4.5. For this research thesis, a software package is needed to analyse the positions of the labourers (Jiang, et al., 2010). Other technological alternatives might not need expensive software other than what is installed on the hardware device.

7.2.4.3 Implementation costs

Similar to the structure of the *probability of completion* criteria, the criteria of implementation costs also has two main focus areas that together form a unit to measure the main criteria. These two areas are the setup costs and the operational costs.

7.2.4.3.1 Setup costs

Depending on the nature of the alternative under question, setup might be needed on a frequent basis. The example of a UWB system might need setup only once and should be done by a trained and capable individual to align the transmitters and receivers in a specific way (Jiang, et al., 2010).

7.2.4.3.2 Operational costs

The total costs of operation are dependent on the alternative under question. For example, the UWB automated system proposed by Giretti *et al.* (2009) does not require a person to give safety related responses in order to give the labourer prior notice of dangerous areas. Other alternatives might need a full time analyst processing the incoming data in real time.

7.2.4.4 Maintenance cost

The maintenance costs are the costs associated with the repair of items that are used as part of the solution alternatives. In this research thesis the alternatives are technology systems and the maintenance costs could relate to any part of the system. The quality of a product and the way in which it is used can largely determine the maintenance cost of an alternative (O'Callaghan, et al., 1992).

7.2.4.5 Consultant cost

Consultants could be used for implementation, operation, training or maintenance of the system. A consultant might be needed due to the specialist nature of the technological systems included in the list of alternatives (Irani, 2002) (Jones & Beatty, 1998).

7.2.4.6 Training costs

Training of personnel can influence costs of operation and maintenance (Irani, 2002). The training costs include the salaries of the employees going on training and the cost of the training programme.

7.2.5 Benefit criteria

The benefit criteria have been tailored to this specific research study which investigated technological options that could assist with the improvement of labour productivity in the construction industry. It was seen from Chapter 4 and Chapter 5 that specific factors influence labour productivity and specific areas can be focused on to improve the problem. For this reason these areas are incorporated into the benefit criteria so that the alternatives' ability to assist with improving the problem can be assessed. The alternatives will be evaluated against these criteria to see how well the alternative can satisfy each criterion.

7.2.5.1 Planning

The decision maker must compare the alternatives according to this criterion by assessing how well the alternatives can assist in the planning of work distribution so that the site area is not crowded at specific areas. Planning of phases and the reduction of rework should also be something to consider when assessing the degree to which the implementation of an alternative can assist in planning. If the implementation of the alternatives can assist with regards to the planning of material locations this should be incorporated when assessing the alternative with this criterion.

7.2.5.2 Data collection

The data collection criterion considers the alternatives' ability to provide timely, accurate data that could assist with productivity improvement. If the alternative can provide legal data such as how an accident happened or when a person was at a specific place during the day, this should be incorporated into this criterion.

7.2.5.3 Control

The ability of the alternative to assist with security control and situation awareness should be assessed within this criterion. The ability to control times of personal breaks as well as late starts or early quits should also be assessed within the control criterion. Control can also be improved by tracking working hours, leave and the remuneration of the workforce and the alternatives' ability to assist these control mechanisms should also be assessed within this criterion

7.2.5.4 Scheduling

The scheduling assistance provided by the alternatives should be assessed based on the ability to reduce stop-and-go operations and improvement of transitioning between different work tasks. The ability to reduce work approval delays and the management of concurrent operations are two attributes that also need to be incorporated into the scheduling criteria assessment of the alternatives. If the alternative can improve the management of multiple shifts and overtime of workers, it should be assessed within the scheduling criterion.

7.2.5.5 Procurement Management

Assessment of the alternatives with regard to this criterion should include the ability of the alternative to reduce stacking of trades, improve team communication, crew build-up and optimizing the size of the crew.

7.2.5.6 Individual

The degree to which the implementation of the alternative can improve the individuals' attitude, personality and safety consciousness should be accounted for using this criterion. If the alternative is able to reduce interruptions and the unlearning curve then this must also be assessed using this criterion. If the implementation of the alternative improves education and training and increases the inputs of workers with regards to work procedures and methods, it should be accounted for using this criterion.

7.2.5.7 Safety

According to Giretti *et al.* (2009) the level safety of the workforce can be increased with the implementation of the technological alternatives identified in section 6.1. Therefore, safety improvements are seen as a criterion with which to assess alternatives. The degree to which the implementation of the alternative can improve safety should be assessed using this criterion.

7.2.5.8 Motivation

Motivation of the workforce can be improved by reducing the amount of control mechanisms noticed by the workforce, increasing the workers accountability and by providing performance reports. Additionally giving individuals more difficult tasks and more authority can also improve motivation. The alternatives' ability to increase motivation should therefore be assessed using these areas within this criterion.

7.2.5.9 Environment

The degree to which the implementation of the alternative can manage the temperature and humidity, keep noise levels tolerable and keep the work environment organized needs to be assessed with this criterion.

7.2.5.10 Physical limitations

The physical limitations criterion is characterized by the potential benefits which the implementation of the alternative can provide in terms of saving energy of the workforce. The degree to which the implementation of the alternative influences the intake of nutrition by the workforce should also be assessed within this criterion.

7.2.5.11 Discipline

Discipline is the criterion that assesses the degree to which the use of the alternative can reduce absenteeism and turnover of staff. Strict monitoring technology, used daily can assist with determining who is absent on which days, so that corrective action can be taken.

7.2.5.12 Handling

The ability to improve the ability to locate and determine the need of tools and materials needs to be assessed within this criterion.

7.2.5.13 Site layout

Within this criterion, the alternatives should be assessed with regards to the ability to provide data that can improve site layout and planning.

7.2.6 Summary of the criteria evaluating technological investments

This section described the different criteria categories used in technology investment decisions namely external -, internal -, risk -, cost -, and benefit criteria. The discussions of the sections within these categories explain how to assess the alternatives' ability to have a positive influence on the operations of the business. Some examples were also incorporated into the description to further the understanding of the criteria.

These criteria discussed will support structured decision making with regarding the choice of technology investments specifically aimed at improving labour productivity. The use of multi-criteria decision making models that can incorporate all of these criteria will be discussed in the following section.

7.3 Making use of multi-criteria decision models

Multi-criteria decisions is regarded by Triantaphyllou, Shu, Nieto-Sanchez and Ray (1998) as a well-known branch of decision making among decision makers. According to Kahraman (2008), there are two distinct categories of multi-criteria problems. These two categories are Multiple Criteria Discrete Alternative Problems (MCDAP) and Multiple Criteria Optimization Problems (MCOP).

Examples of MCDAP include selecting a supplier of equipment, choosing between investing or not investing and selecting technological alternatives for development (Kahraman, 2008). MCOP, on the other hand focuses on a much larger selection of alternatives. The sets of alternatives are often described by equations and inequalities (Kahraman, 2008). Examples of these problems include the planning of a river basin, energy planning and an engineering component design (Kahraman, 2008).

In this research study there is only a specific number of alternatives that need to be evaluated and consequently the problem at hand is a MCDAP.

There are different methods of attempting multi -criteria problems and they are dependent on the amount and type of data. Webster (1998) classified the different methods as deterministic, stochastic or fuzzy. Many researchers have investigated the relevance of specific methods for specific decision making fields (Triantaphyllou, et al., 1998) (Chou, et al., 2006) (Sari, 2013) (Schniederjans, Hamaker, Schniederjans, 2010) (Pohekar & Ramachandran, 2004) (Zanakis, Solomon, Wishart and Dublish, 1998) (Karni, Sanchez and Tummala, 1990).

The different methods that were discussed in these different publications are:

- Analytical hierarchy Process (AHP) in various forms and revisions
- Simple additive Weight (SAW)
- Weighted sum model (WSM)
- Weighted product model (WPM)
- Multiplicate Exponential Weighting (MEW)
- ELimination Et Choix Traduisant la REalite (ELECTRE)
- Technique for Preference by Similarity to the Ideal Solution (TOPSIS)
- Fuzzy multi criteria method

Most of the publications investigated, supported the use of the AHP method and stated that this method is the most commonly used method (Pohekar & Ramachandran, 2004; Karni *et al.*, 1990; Chou *et al.*, 2006; van der Merwe, 2013; Sarin 2013). However, Chou *et al.* (2006) and Sari (2013) utilized the benefits of the AHP and integrated the fuzzy approach within the same method to eliminate some of the shortcomings of the AHP method. Some of the shortcomings that were overcome with the inclusion of the fuzzy model approach were as follows:

- The AHP utilises crisp values to score the alternatives which means that a single numerical value is used. The fuzzy approach gives the analyser the opportunity to make use of linguistic terms, such as equal, moderately, strongly and absolutely etc., to describe the rating given to an alternative. This linguistic rating can be translated into a range rather than a crisp number. Chou *et al.* (2006) stated that this makes the expression of feelings experienced by the experts, rating the alternatives, easier.
- Mirani and Lederer (1998) stated that evaluating the feasibility of information technology is subjective and that it is unrealistic to give crisp values to data that is fuzzy or unclear. They stated that giving a range value to the judgement with a fuzzy approach is more appropriate.
- Some of the criteria used in multi criteria decision making is qualitative and a single numerical value can therefore not be used. The fuzzy approach provides the platform for qualitative rating due to the range values it gives users (Chou, et al., 2006).
- The AHP method gives no indication of the difference or overlap between alternatives within each criterion and only rates the relative importance thereof.

Furthermore, Kahraman *et al.* (2003) explained that the inclusion of the fuzzy logic has the following benefits:

- Fuzzy logic helps deal with vagueness of human thought.
- Fuzzy logic helps in representing vague data but still has a mathematical domain to enable the data to be compared and evaluated.
- Fuzzy helps the natural expression of knowledge on real world problems which have inevitable 'noise' and vagueness.
- Decision makers are more susceptible to provide confident inputs with the use of range values such as those used in fuzzy numbers.

Chou *et al.* (2006) stated that multi-criteria decisions should be made with a single, complex model. However, if the amount of criteria mentioned in section 7.2 needs to be incorporated within one decision model, the model might become difficult to understand and confuse the decision makers (Chou, et al., 2006). Farbey, *et al.* (1993) argues that incorporation of all criteria within one model will be a difficult task. However Farbey, *et al.* (1993) also partially attributes the high rate of technology investment failures to the lack of such an all-encompassing model that is easy to use. Chou *et al.* (2006) stated that a technology investment decision model needs to comply with the following requirements:

The model needs to 1)incorporate the opinions of the stakeholders in every level of the business,2)integrate the risk, benefit and cost criteria into one model,3)have the flexibility to change with regards to weights given to criteria, 4)combine quantitative and qualitative decision making into one model and 5) be easy to use and save time.

Computer technology has made the complex problem of technology evaluation more understandable and user friendly. Computers have assisted in making it easier to implement Multi-Criteria Decision Models (MCDM), and Kirkwood (1997) stated that MCDM calculations can be done faster and more accurate if, for instance, spreadsheets are used.

Chou *et al.* (2006) and Sari (2013) successfully integrated the AHP and fuzzy multi criteria decision models to incorporate the large amounts of criteria associated with technology investments and still managed to keep the use thereof simple and understandable. The fuzzy-AHP multi criteria decision model therefore satisfies the requirements of Chou *et al.* (2006) and will therefore be discussed in the following section.

7.4 Using a Fuzzy-AHP multi-criteria decision model

Decision makers usually take diverse criteria into consideration when making real life decisions. The criteria of this research were described in section 7.2 and are seen to be hard to quantify and are imprecise. Jimenez, Arenas, Bilbao and Rodriquez (2009) stated that the fuzzy logic approach is suited to model these situations.

Chou *et al.* (2006) broke down the use of a fuzzy- analytical hierarchy process for decision making into ten steps. These steps are shown in Table 7.1 and discussed in detail in the sections that follow. Appendix H shows an example of how such a fuzzy-AHP MCDM is implemented.

Table 7.1 - Summary of the steps to rank alternatives with a fuzzy-AHP model (Chou, *et al.*, 2006).

Step 1	Identify a weighting and scoring team
Step 2	Define the criteria for the evaluation
Step 3	Identify and investigate possible alternatives
Step 4	Choose a linguistic scale for weighting and then perform a pair-wise comparison
Step 5	Construct the different fuzzy reciprocal matrices
Step 6	Determine the final aggregated fuzzy reciprocal matrix
Step 7	Determine the local and global weights of criteria
Step 8	Choose a linguistic scale for scoring and perform the scoring of alternatives
Step 9	Aggregate the final score matrix and determine the final score of each alternative
Step 10	Use a de-fuzzification formula to determine the rankings of the alternatives.

7.4.1 Identify a weighting and scoring team

Chou *et al.* (2006) used two exclusive teams that performed the two tasks of weighting the criteria and scoring the alternatives. In the publication of Chou *et al.*(2006) one team performed the weighting of the criteria and another team performed the scoring of the proposed alternative solutions. The two teams were selected in such a way that the different levels of stakeholders described in section 7.1.2 were taken into account. The compositions of the teams were, therefore, a mixture that included top management, executive managers, financial staff, IT managers and users. After the scoring and weighting had been done by the teams, the analyser can see from the data what the priorities of the different stakeholders are and incorporate these in the final decision (Chou, et al., 2006).

The team composition is an important aspect to consider due to the fact that many technology investments fail due to the lack of complying with the needs of all parties affected by the investment (Chou, et al., 2006). User rejection is one of the main examples of this phenomenon and it is advised that more than one user be included in the teams because they have a vested interest to choose the best working alternative (Chou, et al., 2006).

Besides representing a process and being able to say that everyone had their chance to provide their input in the decision, Chou *et al.* (2006) stated that there are five reasons why specific members should be selected in these teams. These reasons are as follows:

1. Including the executive manager will ensure that the proposed projects/alternatives do not conflict with the business strategy.
2. Including technology experts ensures that the design, methodology and technological architecture associated with the alternative are feasible.
3. Including the accounting experts will ensure that the cost-benefit ratios and the availability of funds are considered during decision making.
4. Including auditors will help with the implementation and monitoring of considerations because they understand the purpose of the projects/alternatives.
5. Including external consultants will add objective advice to the decision making process

Once the composition of the teams is clear, the responsibilities of the teams should be clarified. The weighting team is responsible to give relative weights to the list of criteria. Depending on the problem at hand the weights can refer to the importance, preference or likelihood of the criteria (Chou, et al., 2006). Given the labour productivity problem and the custom set of criteria, the weights in this research thesis refer to the importance of that criterion in determining the best alternative for the company. The responsibility of the scoring team is to evaluate the performance of the alternative with regard to the criteria used in the decision making procedure (Chou, et al., 2006).

The weighting and scoring team members have to give weights to the criteria or rate the performance of alternatives by using linguistic terms such as those seen in Table 7.2. Using linguistic terms makes it easier to express the feelings of the team members than assigning crisp values (Chou, et al., 2006). The weights given to the criteria should reflect the culture of the organisation or how important that criteria is to the company. This means that if the company has a long term vision and strategy, the weighting of criteria could be done only once for all the decisions (Chou, et al., 2006). However the model is flexible enough that it allows the weights to be changed with each decision if it is needed.

7.4.2 Define criteria for the evaluation

The structure of the criteria given in section 7.2 has been derived from an extensive study on different decision making criteria for business and technology decisions. This framework can therefore be used as a basis for future decision making procedures (Chou, et al., 2006).

The framework can be changed to suit specific company policies or objectives and it is advised that especially the benefit criteria are tailored based on the specific problem at hand.

In this research thesis the factors influencing labour productivity were identified in Chapter 4. After these factors had been identified, the factors were analysed to identify shortcomings and, therefore, identifying the needs for productivity improvement. The needs for improvement formed the basis of the benefit criteria.

After the different categories of criteria had been populated with criteria, a structure was given to the criteria. This allowed criteria which are dependent on each other to be accounted for. This was achieved by creating different levels of criteria. An example of dependent criteria is the 'Probability of completion' criterion that is dependent on three sub-criteria. The structure used with this research thesis was that of the AHP and the criteria can be described as being imbedded into a hierarchy (Saaty, 1990).

This research thesis has criteria on three levels and can be seen in Figure 7.3. The first level consists of the categories of criteria and highlighted in orange and include external -, internal -, risk -, cost – and benefit criteria. The second level of criteria includes all the criteria directly connected to the first level of criteria and are highlighted in yellow. 'Probability of completion' and 'Probability of benefit' are, for example, two criteria that are directly connected to a first level criteria (Risk criteria), and are, therefore, second level criteria. The third level criteria are defined by criteria that are directly connected to the second level criteria and are highlighted in green. 'Manpower', 'Skill of IT staff' and 'Maturity of new technology' are criteria that are directly connected to a second level criteria (i.e. Probability of completion), and are, therefore, third level criteria.

For the purpose of this research a criterion will be denoted by the symbol C and depending on the amount of criterion compared at a time the collection of criteria will be (C_1, C_2, ... ,C_n).

7.4.3 Identify and investigate possible alternatives

This step requires the decision maker to identify and investigate possible alternatives that can solve the problem at hand. In this research thesis the investment of technology was investigated based on the literature review in Chapter 2. The benefits that technology has produced in other industries were seen as the inspiration to investigate technology investments in construction. After the main areas of concern had been identified, one common problem was identified that formed the basis of the area of concern. This problem was the lack of control over, or management of human behaviour. Examples of other industries that succeeded to manage and control human behaviour to benefit both the individual and the organisation were seen as the source of technology solutions.

If a large number of alternatives are identified, a screening process should be used to either categorise alternatives or filter alternatives with methods such as the FuGle method (du Preez, et al., 2010). The FuGle model combines strategy, people and culture of the business in its first phase. The first phase aims to identify opportunities and creating a prospects portfolio. The second phase of the FuGle model utilises information and knowledge gathered as well as the organisational structure to evaluate the ability to commercialise the alternatives identified in the first phase. The FuGle process makes use of different filters within the two phases, which eliminate the alternatives which do not appear feasible.

For the purpose of this research an alternative will be denoted by the symbol A and depending on the amount of alternatives a the collection of alternatives will be (A_1, A_2, ... ,A_a).

7.4.4 Choose a linguistic scale for weighting and then perform a pair-wise comparison

As stated earlier, it is easier for experts to express their opinions in linguistic terms because a range value is more suitable to qualitatively express the subjectivity of the team members' impressions (Chou, et al., 2006). Therefore, linguistic terms are used instead of crisp values to express the degree to which preference is given to a specific item when comparing it with other items. In order to translate the linguistic term into a value range, fuzzy numbers are used.

Fuzzy numbers represent a range rather than a crisp value and according to Liang and Wang (1994) triangular fuzzy numbers (TFNs) are the most commonly used.

A fuzzy number Ň can be parameterized by a triplet Ň = (*l; m; u*) where the parameters *l*, *m* and *u* represent the lower limit, the most likely value and the upper limit of the TFN (Tavakkoli-Moghaddam, Mousavi, Hashemi, 2011). Zimmermann (1996) characterised a fuzzy number Ň by using the membership function $\mu_{Ň}(x)$. This membership function is described in equation 7.1. A fuzzy number can be graphically represented as seen in Figure 7.4.

The linguistic ranges used in fuzzy logic literature are summarised in Table 7.2 (Sadeghi, Moghimi, Ramezan, 2009) (Chou, et al., 2006) (Sari, 2013) (Saaty, 1990). There are only six terms listed but there are eleven different TFNs that can be used. The reason for the difference in amount of linguistic terms and TFNs will be described in the following section. These linguistic terms are used during the pair-wise comparison of the criteria. The pair-wise comparison procedure will be discussed in the next section.

$$\mu_{Ň}(x) = \begin{cases} 0 & ; \quad x \leq l \\ \dfrac{x-l}{m-l} & ; \; l \leq x \leq m \\ \dfrac{u-x}{u-m} & ; \; m \leq x \leq u \\ 0 & ; \quad x \geq u \end{cases} \quad \ldots\ldots\ldots 7.1$$

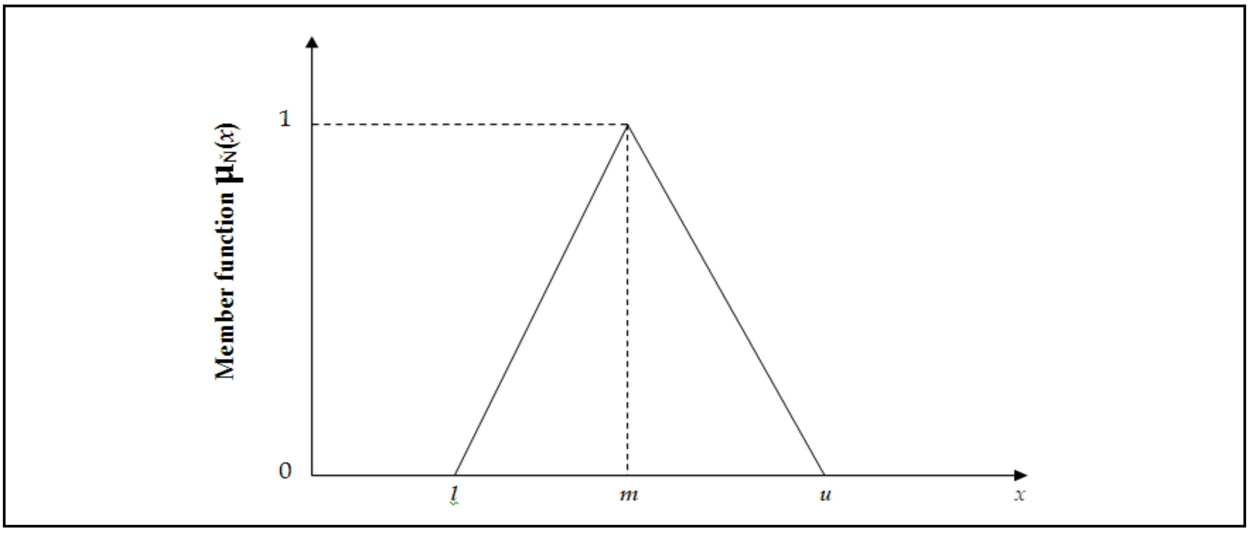

Figure 7.4- Graphical representation of a Fuzzy triangular number (FTN) (Tavakkoli-Moghaddam, et al., 2011).

7.4.5 Construct the different fuzzy reciprocal matrices

Each member of the weighting team has to construct a fuzzy reciprocal matrix and this involves comparing the list of criteria that is part of the decision making process. The construction of a fuzzy reciprocal matrix requires that the individual compare each of the criteria within one level, according to their relative importance, with respect to the parent criteria in the upper level (Saaty, 1990). The different criteria levels are dependent on the structure of the list of criteria and the amount of sub-criteria (Saaty, 1990).

Table 7.2 - Scale used to convert linguistic weighting ratings to corresponding fuzzy numbers (Chou, et al., 2006) (Sari, 2013) (Saaty, 1990)

Comparing criteria *i* to criteria *j* in terms of their relative importance to the overall criteria.			
Linguistic	**Explanation**	**Triangular fuzzy numbers (TFN)**	**Inverse of TFN**
Equal importance (EI)	*i* and *j* have equal importance	$(1 ; 1 ; 1)$	$(1 ; 1 ; 1)$
Weakly more important (WMI)	*i* and *j* have similar importance but *i* is more important than *j*	$(\frac{1}{2} ; 1 ; \frac{3}{2})$	$(\frac{2}{3} ; 1 ; 2)$
Moderately more important (MMI)	Experience and judgement slightly favour *i* over *j* in terms of importance	$(1 ; \frac{3}{2} ; 2)$	$(\frac{1}{2} ; \frac{2}{3} ; 1)$
Strongly more important (SMI)	*i* is favoured strongly over *j* in terms of importance	$(\frac{3}{2} ; 2 ; \frac{5}{2})$	$(\frac{2}{5} ; \frac{1}{2} ; \frac{2}{3})$
Very strongly more important (VSMI)	*i* dominates j in terms of importance	$(2 ; \frac{5}{2} ; 3)$	$(\frac{1}{3} ; \frac{2}{5} ; \frac{1}{2})$
Absolutely more important (AMI)	*i* has the highest degree of dominance over j in terms of importance	$(\frac{5}{2} ; 3 ; \frac{7}{2})$	$(\frac{2}{7} ; \frac{1}{3} ; \frac{2}{5})$

During the comparison the team member selects specific linguistic terms to describe the relative importance of one criterion over another. This comparing procedure is called the pair-wise comparison. The pair-wise comparison in this research thesis is used to determine the relative importance of each criterion in the decision making process and will now be discussed.

Pair-wise comparison compares a list of items, in pairs of two, with the goal to rank the list of items in order of importance. Two items are compared to each other and a degree of preference is given to the one item (van der Merwe, 2013).

The degrees of preference used in this research are the linguistic terms seen in Table 7.2. Six of these linguistic terms are listed in Table 7.2 of which the last five have inverse functions. This gives the individual a further five degrees of preference during the comparison. By adding the extra five degrees of preference to the six in Table 7.2 the individual has eleven different degrees of preference for each comparison.

Pair-wise comparison utilizes matrices to compare each criterion with the rest of the list. These matrices used are called fuzzy reciprocal matrices and will be populated by the linguistic terms describing the comparisons (Sari, 2013).The number of individuals in the weighting team is denoted by K. The symbol k symbolises one of these members and the k^{th} individual's fuzzy reciprocal matrix will therefore be denoted by [FRM^k] (Sari, 2013). Equation 7.2 shows the structure of the k^{th} individual's fuzzy reciprocal matrix.

Table 7.3 - Summary of the different FRM matrices each member of the weighting team must complete.

Matrix Number	Level of criteria compared	Criteria being compared	Level of parent criteria	Parent criteria
1	3	Manpower considerations	2	Probability of completion
		Skill of IT staff		
		Maturity of new technology		
2	3	Setup costs	2	Implementation costs
		Operational costs		
3	2	Partner alliance	1	External criteria
		Commit to government requirements		
		React to or compete with other companies		
4	2	Organisational learning	1	Internal criteria
		User's Requirements		
		Integration with existing IT systems		
		Impact of organisational restructure		
		Assist to achieve corporation goal		
		Assist to make management decision		
5	2	Probability of completion	1	Risk criteria
		Probability of benefit		
6	2	Hardware costs	1	Cost criteria
		Software costs		
		Implementation costs		
		Maintenance		
		Consultant cost		
		Training costs		
7	2	Planning	1	Benefit criteria
		Data collection		
		Control		
		Scheduling		
		Procurement management		
		Individual		
		Safety		
		Motivation		
		Environment		
		Physical limitations		
		Discipline		
		Handling		
		Site layout		
8	1	External criteria	NA	Investment Criteria
		Internal criteria		
		Risk criteria		
		Cost criteria		
		Benefit criteria		

The structure of the criteria seen in Figure 7.3 will require the team members to each conduct eight pair-wise comparisons within the different levels of criteria and will therefore have to construct eight matrices (Saaty, 1990). Table 7.3 shows how the eight different levels of criteria should be grouped into matrices for pair-wise comparison.

The weighting team will conduct the comparisons of the criteria using these matrices and the size of the matrix (*n*x*n)* depends on the amount of criteria compared (symbolised by *n).* The last group of criteria (Matrix number 8) seen in Table 7.3 consists of five criteria to be compared and the matrix will therefore be a 5x5 matrix.

$$[\mathrm{FRM}^k]_{nxn} = \begin{bmatrix} 1 & C_{12}{}^k & C_{13}{}^k & C_{14}{}^k & \cdots & C_{1n}{}^k \\ C_{21}{}^k & 1 & C_{23}{}^k & C_{24}{}^k & \cdots & C_{2n}{}^k \\ C_{31}{}^k & C_{32}{}^k & 1 & C_{34}{}^k & \cdots & C_{3n}{}^k \\ C_{41}{}^k & C_{42}{}^k & C_{43}{}^k & 1 & \cdots & C_{4n}{}^k \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{n1}{}^k & C_{n2}{}^k & C_{n3}{}^k & C_{n4}{}^k & \cdots & 1 \end{bmatrix} \quad \ldots 7.2$$

If criteria *i* (C_i) is compared to criteria *j* (C_j) by the k^{th} member of the weighting team, it is denoted $C_{ij}{}^k$. If, with this comparison, C_i is strongly more important than C_j the linguistic rating of the comparison will be Cij^k = SMI. Using Table 7.2 the TFN will be as follows: $C_{ij}{}^k = (\frac{3}{2}, 2, \frac{5}{2})$. If, however, C_i is compared to C_j and C_j is strongly more important than C_i the inverse FTN of SMI in Table 7.2 will be used and therefore the comparison will be denoted as follows: $C_{ij}{}^k = (\frac{2}{5}, \frac{1}{2}, \frac{2}{3})$.

From the details in the previous paragraph, it can be deduced that the TFN of $C_{ji}{}^k$ is the inverse of the TFN of $C_{ij}{}^k$ (Sari, 2013) (Saaty, 1990). For this reason only the upper half of the [FRM^k] has to be compared by the weighting team. The lower half of the [FRM^k] can be calculated by using the inverses of the upper half's TFNs (Saaty, 1990). By applying this inverse rule the [FRM^k] matrix in equation 7.2 can be rewritten as in equation 7.3.

After each of the individuals has completed the comparison and populated their respective [FRM^k] matrices with the linguistic terms, the terms are converted to the corresponding FTNs. This step can be performed by a spread sheet or a software package (Kirkwood, 1997). If all the individuals' fuzzy reciprocal matrices are fully populated with TFNs the next step of aggregating the final fuzzy reciprocal matrix can be done.

$$[\mathrm{FRM}^k]_{nxn} = \begin{bmatrix} 1 & C_{12}{}^k & C_{13}{}^k & C_{14}{}^k & \dots & C_{1n}{}^k \\ {}^1/_{C_{12}}{}^k & 1 & C_{23}{}^k & C_{24}{}^k & \dots & C_{2n}{}^k \\ {}^1/_{C_{13}}{}^k & {}^1/_{C_{23}}{}^k & 1 & C_{34}{}^k & \dots & C_{3n}{}^k \\ {}^1/_{C_{14}}{}^k & {}^1/_{C_{24}}{}^k & {}^1/_{C_{34}}{}^k & 1 & \dots & C_{4n}{}^k \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ {}^1/_{C_{1n}}{}^k & {}^1/_{C_{2n}}{}^k & {}^1/_{C_{3n}}{}^k & {}^1/_{C_{4n}}{}^k & \dots & 1 \end{bmatrix} \dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots..7.3$$

7.4.6 Determine the final aggregated fuzzy reciprocal matrix

If the weighting team consists of only one individual (K = 1) that individual's fuzzy reciprocal matrix is the same as the final aggregated fuzzy reciprocal matrix. However, if there are more members, as proposed in this research, the final aggregated fuzzy reciprocal matrices should be calculated. This is shown in the following paragraphs.

The goal of determining the final aggregated fuzzy reciprocal matrix is to combine the inputs of all the team members into one aggregated 'voice' that reflects the importance of the different criteria. This aggregated 'voice' is thereafter used to rank the criteria in terms of importance both locally and globally. Local importance refers to the importance of the compared criteria in a single pairwise comparison. Global importance refers to the relative importance of the criteria to all of the criteria in the criteria structure.

If the final aggregated fuzzy reciprocal matrix is calculated for a team consisting of more than one individual, it can no longer be seen how the individuals perceived the local and global importance of the criteria. This information can be useful to determine what the priorities are of the different team members within different business levels. This information can, however, be calculated for each individual by following the steps as explained in sections 7.4.1 to 7.4.7 but assuming that the weighting team only consist of one member.

In the case of this research thesis the use of a team consisting of various individuals is proposed. This is done based on the successes of the implementation of bigger teams by Chou *et al.* (2006) and Sari (2013). For this reason it is assumed that a method for calculating the final aggregated fuzzy reciprocal matrix from a bigger team should be provided.

It is therefore necessary to aggregate all the individuals' fuzzy reciprocal matrices into one matrix denoted $[\mathrm{F\overline{R}M}]$. In Table 7.3 it was shown that there are eight different fuzzy reciprocal matrices that each team member should complete. For this reason there will be eight final aggregated fuzzy reciprocal matrices. Each entry within these matrices is calculated by geometric means and makes use of equation 7.4.

$$\bar{C}_{ij} = (C_{ij}^{1} \otimes C_{ij}^{2} \otimes ... \otimes C_{ij}^{k})^{\wedge(1/K)} \text{ .... } 7.4$$

In equation 7.4, $\bar{C}_{ij}$ symbolises the aggregated value of all the team members' comparison of C_i with C_j. Due to the fact that the individuals' fuzzy reciprocal matrix consist of TFNs, $\bar{C}_{ij}$ will also be a TFN. The symbol C_{ij}^{1} in equation 7.4 represents the first individuals' TFN of the comparison of C_i with C_j. The operator symbol ⊗ refers to fuzzy multiplication. Fuzzy multiplication of two TFNs $\breve{A}=(l_a; m_a; u_a)$ and $\breve{B}=(l_b; m_b; u_b)$ is calculated as shown in equation 7.5. The rule of powers with fuzzy numbers is explained with equation 7.6. Fuzzy addition is symbolised with the operator ⊕ and is explained in equation 7.7.

$$\breve{A} \otimes \breve{B} = (l_a \text{x} l_b; m_a \text{x} m_b; u_a \text{x} u_b) \text{ .... } 7.5$$

$$\breve{A}^{\wedge(1/K)} = (l_a^{\wedge(1/K)}; m_a^{\wedge(1/K)}; u_a^{\wedge(1/K)}) \text{ .... } 7.6$$

$$\breve{A} \oplus \breve{B} = (l_a+l_b; m_a+m_b; u_a+u_b) \text{ .... } 7.7$$

Each of the aggregated values for all the entries in the final aggregated fuzzy reciprocal matrices should be calculated with equation 7.4. Depending on the number of criteria, number of team members and the number of the final aggregated fuzzy reciprocal matrices required, this could require a large amount of repetitive calculations. Kirkwood (1997) is of the opinion that these calculations can be conducted faster by using spreadsheets or computer software.

7.4.7 Determine the local and global fuzzy weights of criteria

The first step of determining the fuzzy weight for each of the criteria is to determine the geometric row means using the aggregated values within the [F$\overline{\text{R}}$M] matrices. The geometric row means r_i is calculated by using the method proposed by Buckley (1985) and this method uses equation 7.8.

$$r_i = (C_{i1} \otimes C_{i2} \otimes ... \otimes C_{in})^{\wedge(1/n)} \text{ .... } 7.8$$

The symbol r_i represents the geometric row mean of row i and will be expressed as a TFN. If there are n amount of rows in the [F$\overline{\text{R}}$M] the range of i is i = (1, 2, ..., n). This means that there will be n number of TFN's, each relating to the different rows of the [F$\overline{\text{R}}$M] matrix. Each of these geometric row values (r_i) is related to the criteria of that row C_i. The geometric row means should be calculated for each of the eight [F$\overline{\text{R}}$M] matrices. Given the criteria-structure of this research thesis, eight final aggregated fuzzy reciprocal matrices will have to be calculated.

These geometric row means have to be normalised in order to determine the local weights of the criteria within that matrix. Equation 7.9 is used to normalise the geometric row means and to determine the local weights of the criteria being compared in that matrix.

$w_i = r_i \otimes (r_1 \oplus r_2 \oplus \ldots \oplus r_n)^{\wedge(-1)}$ 7.9

The symbol w_i represents the local weight of criteria i (C_i) within the specific [F$\overline{\text{R}}$M] matrix. The local weights are used for the calculation of the global weights of the criteria. The global weight of criteria i (C_i) is denoted $\overline{w}_i$.

The global weight ($\overline{w}_i$) of criteria i (C_i) is calculated by the fuzzy multiplication of the local weights of all the parent criteria of C_i. The global weight of 'Manpower' will, for example, be calculated by fuzzy multiplication as shown in equation 7.10 (Saaty, 1990) (Sari, 2013) (Chou, et al., 2006).

$\overline{w}_{\text{Manpower}} = w_{\text{Manpower}} \otimes w_{\text{Probability of completion}} \otimes w_{\text{Risk criteria}}$ 7.10

This method of ranking criteria in terms of their global weights is suitable in MCDM (Saaty, 1990) due to the fact that all the criteria should be considered in the decision making process but have relative importance (Chou, et al., 2006).

7.4.8 Choose a linguistic scale for scoring and then perform the scoring of alternatives

After specific global weights have been calculated for the criteria and the criteria have been ranked in order of importance, the next step towards selecting the best alternative can be taken. This requires that the scoring team measures the performance of the alternatives against the criteria. Similar to the weighting team, the scoring team will also make use of linguistic terms to describe the performance of the different alternatives.

A scale for converting linguistic terms to TFNs should be chosen. Chou *et al.*(2006), Sari (2013), Wang and Chang (1995) and Chen (2000) used the scale presented in Table 7.4 to translate linguistic terms to TFN-scores which measure the performance of alternatives.

Given the translation scale in Table 7.4, the scoring of alternatives can be performed by the scoring team. It is the job of the scoring team to assign a linguistic term that represents how well an alternative performs given a specific criterion. The scoring of the alternatives is done on a relative basis and it is therefore necessary that the alternatives are seen alongside each other when comparing their performance with regards to a specific criterion.

Different from the weighting process all the criteria can be listed in a single matrix with a column for each of the different criteria. The different alternatives will form the rows of the matrix. The scoring matrix will have a size of axn with alternatives, Ai ; i=(1,2, ..., a), and criteria, Cj ; j=(1,2, ..., n) (Sari, 2013). Scoring matrices will be completed by each member of the scoring team. The number of individuals in the scoring team is denoted by S. The symbol s symbolises one of these members and the s^{th} individual's score matrix will therefore be denoted by $[X^s]_{ixj}$.

Table 7.4 - Linguistic term scale for scoring the performance of alternatives against criteria (Chou *et al.*,2006; Sari, 2013; Wang and Chang,1995; Chen ,2000).

Linguistic variable	TFN
Very Low (VL)	(0.0 ; 0.1 ; 0.3)
Low (L)	(0.1 ; 0.3 ; 0.5)
Medium (M)	(0.3 ; 0.5 ; 0.7)
High (H)	(0.5 ; 0.7 ; 0.9)
Very High (VH)	(0.7 ; 0.9 ; 1.0)

The s^{th} member of the scoring team's scoring matrix can be seen in equation 7.11. The different criteria will be listed in different columns from 1 to n. The different alternatives will be listed in different rows from 1 to a. Within this matrix, performance scores, in the form of linguistic terms, will be inserted by using Table 7.4.

The symbol x_{ij}^{s} represents the performance score the s^{th} member of the scoring team gives to alternative Ai with regards to criteria Cj. Initially these values of x_{ij}^{s} will be in terms of linguistic terms and need to be translated to TFNs by using the scale in Table 7.4 so that $x_{ij}^{s} = (l_{ij}^{s} ; m_{ij}^{s} ; u_{ij}^{s})$. Given that each member of the scoring team will construct a matrix such as shown in equation 7.11, the members' scores can be aggregated into one final score matrix . The aggregation of this final score matrix is explained in the next section.

$$
[X^s]_{axn} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ \vdots \\ A_a \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & C_3 & C_4 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11}{}^s & x_{12}{}^s & x_{13}{}^s & x_{14}{}^s & \dots & x_{1n}{}^s \\ x_{21}{}^s & x_{22}{}^s & x_{23}{}^s & x_{24}{}^s & \dots & x_{2n}{}^s \\ x_{31}{}^s & x_{32}{}^s & x_{33}{}^s & x_{34}{}^s & \dots & x_{3n}{}^s \\ x_{41}{}^s & x_{42}{}^s & x_{43}{}^s & x_{44}{}^s & \dots & x_{4n}{}^s \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{a1}{}^s & x_{a2}{}^s & x_{a3}{}^s & x_{a4}{}^s & \dots & x_{an}{}^s \end{bmatrix} \end{array} \quad \dots\dots\dots\dots 7.11
$$

7.4.9 Aggregate the final score matrix and determine the final score of each alternative

Aggregating all the scoring matrices formed by the different members of the scoring team is done by geometric means. This is done by using the same method used to aggregate the fuzzy reciprocal matrices of the weighting team members in section 7.4.6. The aggregating step can also be skipped if the scoring team only consists of one individual because the aggregated score matrix will be the same as the scoring matrix calculated by the individual in equation 7.11. However as explained in section 7.4.6, this research proposes that a bigger group of team members is used. For this reason a method will be explained where the scoring team consists out of more than one team member.

Equation 7.4 can be changed slightly to be applicable for calculating the aggregated scores for the aggregated score matrix. Equation 7.12 is used to aggregate the scores of the different matrices created by the scoring team members.

$$
\bar{x}_{ij} = (x_{ij}{}^1 \otimes x_{ij}{}^2 \otimes \dots \otimes x_{ij}{}^s)^{\wedge(1/S)} \quad \dots\dots\dots\dots 7.12
$$

In equation 7.12, $\bar{x}_{ij}$ symbolises the aggregated score of all the team members' performance scores of alternative A_i with regards to criteria C_j. Due to the fact that the individuals' score matrices consist of TFNs, $\bar{x}_{ij}$ will also be a TFN. The symbol $x_{ij}{}^1$ in equation 7.12 represents the first individual's TFN-performance score of A_i with criteria C_j.

In terms of data and the loss of individuals' perceptions, the same accounts for the scoring matrix as for the fuzzy reciprocal matrix explained in section 7.4.6. When aggregating the scoring matrices, the individuals' perspectives of the scores for the alternatives will be lost just as with the fuzzy reciprocal matrices. It is, however, possible to calculate each individual's score for each alternative prior to aggregating the score matrix. This is done by fuzzy multiplication of the global weights of the criterion ($\overline{w}_j$) with the score of the individual x_{ij}^s and summing the values for all the criteria.

However if the aggregated scores ($\overline{x}_{ij}$) are calculated by using equation 7.12, each alternative (A_i) would have a single score for every criteria (C_j). Each of the criteria has an aggregated global weight ($\overline{w}_j$) that has to be accounted for when calculating the alternatives final score.

The final score (R*i*) of an alternative (A*i*) is calculated by using equation 7.13 that sums all the fuzzy multiplications of the aggregated performance scores with the global aggregated weights for each criterion (C_j).

$$R_i = \sum_{j=1}^{n} \overline{x}ij \otimes \overline{w}_j \dots\dots 7.13$$

The final score of each alternative will be a TFN (L*i*; M*i*; U*i*) where L*i* represents the lower score limit, M*i* the most likely score and U*i* the upper score limit. The next step of selecting the best alternative is to use the TFNs of the alternatives together with a de-fuzzification formula to determine the rankings of the alternatives.

7.4.10 Use a de-fuzzification formula to determine the rankings of the alternatives

The translation of TFNs into crisp values (CV) is done with a de-fuzzification formula seen in equation 7.14.

$$CV_i = L_i + \{(M_i - L_i) + (U_i - L_i)\}/3 \dots\dots 7.14$$

The symbol CV_i represents the crisp value of alternative A*i*. The alternative with the highest CV is the most preferred alternative given its performance with regards to the weighted criteria.

7.5 Conclusion

Given the identification procedure and the two proposed alternatives in Chapter 6, it was necessary to look into how decision making is done within businesses and specifically in construction. It was found that a mixture of a logical incrementalism and an interpretative approach exists in top South African construction companies. This means that managers make decisions incrementally while considering an underlying company strategy but they still consult other managers to stay in line with the organisational paradigm.

The difference in level and detail of decisions was also investigated in this chapter. It was found that decisions can be made on a strategic, tactical and operational level. These different levels of decisions involve different employees that operate on different levels of management.

A combination of published articles was used in a procedure to create a criteria structure that is tailored for decision making regarding technology investments for the purpose of improving labour productivity. This procedure utilised the material discussed in previous chapters regarding the concern of low labour productivity and incorporated it in the benefit criteria.

An investigation on different methods of dealing with multiple criteria in decisions was discussed and it was found that the analytical hierarchy process (AHP) was the most commonly used method. However, other researchers have adapted the AHP and integrated it with fuzzy logic to create a fuzzy-AHP multi criteria decision model. This was done to overcome most of the shortcomings of the AHP and to include multiple criteria as well as subjectivity of opinion into one model.

The fuzzy-AHP multi criteria decision model was discussed and explained in detail in this chapter in order to show how it can be used by a company to evaluate identified technological alternatives. Not only does the proposed model incorporate the input of most stakeholders on various levels of management, but it also incorporates the details of the labour productivity problem it needs to solve. The model incorporates risk, benefit and cost into one model and can be used to combine quantitative and qualitative criteria.

The challenging task of evaluating alternatives was broken down into logical and manageable steps so that it is understandable and suitable for computer integration. Computer aid will dramatically shorten the decision making time and make the decision process more user-friendly.

CHAPTER 8

Discussion of research findings and objectives

In this chapter the objectives and findings of the research, which centred on the process of technology investment decisions in the construction industry, are presented. A discussion of the research findings is presented and followed by a synthesis of the findings. The research objectives as set out in the introductory chapter will be discussed, which include six questions and a hypothesis. After the discussion of the research objectives, the advantages and shortcomings of the proposed process will be stated.

8.1 Discussion of research findings

This research study set out to investigate how technology can be incorporated in the construction industry. This was achieved by investigating the application of a process to assist technology investment decisions to solve specific areas of concern. Labour productivity was identified as an area of concern and it was used to establish and calibrate the process. The steps of the process are as follows:

- Step 1- Identification of areas of concern
- Step 2 -Dissect the identified area of concern
- Step 3 –Identify technological alternatives
- Step 4 –Evaluate technological alternatives

These steps were executed during the research study and were discussed in detail in preceding chapters. The step sequence ties in with the structure of the research identified in section 1.5. The process and its findings are discussed in the following sections:

8.1.1 Step 1- Identification of areas of concern

The identification of areas of concern which was discussed in Chapter 3 had been done by interviewing managers with experience in different divisions of civil engineering construction. These interviews were aided by a list of areas of concern by Assaf and Al-Hejji (2006). This long list, comprising of 73 areas of concern, were screened and 49 areas of concern were given to the four interviewees. The interviewees ranked the 49 areas of concern and only the top 9 most influential areas of concern were included in a survey and given to a larger group of 38 experienced managers to assess. The shortened list of areas of concern had been assessed according to the impact each area of concern has on project time, - cost, - quality and project risks by the delegates at the 2012 Construction Management Programme (CMP) hosted at Stellenbosch. The aim of the survey and the ranking of areas of concern were to identify the current areas of concern with the biggest impact on project delivery in South

African construction. The areas of concern had been ranked with the assessment data from the survey and low labour productivity was identified as the most influential area of concern.

8.1.2 Step 2 -Dissecting the identified area of concern:

The next step performed in the research study was to dissect low labour productivity in construction and this was performed in Chapter 4. This dissection involved evaluating whether the labour productivity is a major issue in other countries or companies as well. This result of the CMP survey differed from other similar surveys conducted in other countries and labour productivity was not the top area of concern (Assaf & Al-Hejji, 2006). However, the results had been validated by the effects and implementation of the Expanded Public Works Program (EPWP) in South Africa. In 2004 the EPWP was launched by the department of public works and is currently still being implemented. The aim of this program is to contribute to the Government's Policy Priorities to fight against crime and corruption through inclusive economic growth (The Department of Public Works, 2013). The EPWP appeals particularly to the infrastructure development industry to use labour intensive construction methods. The aims of the EPWP are in line with creating a better South Africa and should be seen as another variable that contractors have to take into account when coming up with an innovative solution.

The realisation that labour will continue to be used in construction in South Africa voided the possibility to eliminate labour in construction. This steered the dissecting of the area of concern to identify how labour productivity is measured and what influences labour productivity. This investigation provided many ways in which productivity can be defined, such as economic -, activity - and project specific models. Five different measuring techniques were also identified and the benefits and limitations of each model were discussed. Factors that influence labour productivity were also identified to help determine the source of the problems. The findings of the investigation on labour productivity in construction showed that factors influencing labour productivity can be grouped into three categories. These categories include management practices, labour effectiveness and material timeliness. It was seen that many of these factors are manageable whilst others should just be considered when measuring productivity. Management practices was the category that had the most potential to be improved and 50% of all the productivity inhibiting factors are related to this category.

The dissection of labour productivity made it easier to identify aspects where improvements can be made. This was performed in Chapter 5 where the restrictions with regards to the improvement of labour productivity were discussed. A better understanding of labour productivity therefore formed the basis on which improvements were based.

8.1.3 Step 3 –Identify technological alternatives:

In Step 3 of the process, which was discussed in Chapter 6, the findings of Chapter 4 and Chapter 5 were considered to determine the crux of the problem with low productivity of labour. Dissecting the area of concern provided two realisations and the first realisation was that increased monitoring of labourers is needed to improve the quality and amount of usable data for productivity management. The second realisation was that the behaviour of the labourers must be optimised.

The identification of alternatives was done by taking these two realisations into consideration with lessons learned from similar examples within other industries. Industries such as automotive manufacturing, agriculture and many others have adopted various innovation cultivating strategies to identify technological solutions to problematic areas identified. Research was conducted to identify technological solutions for similar problems in other industries. Traffic lights and traffic cameras did, to some extent, manage to dictate and optimise motorist's behaviour. The management of professional sports teams is an example of another industry that managed to improve the behaviour of players on a field by closely monitoring their behaviour and movements.

By utilising the realisations derived from the investigations of Chapter 4 and Chapter 5 of this study, and combining it with these two examples of other industries, wireless tracking and visual analysis were identified as possible technological solutions. By improving monitoring of resources and capturing more data, with either one of these alternatives, labourers' behaviour could be improved. Furthermore, better data could be acquired for improved productivity measurement and management.

8.1.4 Step 4 – Evaluate technological alternatives:

The fourth and final step of this process was described in Chapter 7 and involved the evaluation of solution alternatives. To make a decision or investment, the effects of the decision or investment need to be quantified. This is done to determine how the costs compare to the benefits of the investment. Section 8.3.1, explains exactly how this quantifying procedure works in detail.

The evaluation process was started by selecting criteria for making the investment decision. The effects which the labour productivity concern required, in order to improve the concern, were incorporated in the benefit criteria. This was done because the technological investments should aim to improve the low labour productivity concern.

After the criteria had been tailored, the different strategies of businesses were investigated and the different levels of decision making were identified. Different models that incorporate multiple criteria and the opinions of different stakeholders were also researched. Research showed that, when having to combine technology alternatives, multiple criteria and the opinions of different business stakeholders in a decision, a fuzzy-AHP MCDM is the most appropriate method to use. A fuzzy-AHP MCDM can utilise these elements and quantify the effects of the different decisions to help deciding between specific technological investments.

8.1.5 Summary of research findings discussion

From the discussion of the research findings it can be deducted that a specific process was used to research the labour productivity area of concern. This process shows how the labour productivity concern was identified and analysed so that wireless tracking and visual analysis could be identified as two possible solutions. The study determined how to effectively incorporate multiple criteria and different stakeholders in the evaluation of the alternatives in order to solve the productivity problem. A synthesis of the research findings is presented in the following section.

8.2 Synthesis of research findings

A synthesis of the research findings is presented in this section to demonstrate how this process is applicable to other situations. The steps of the process is summarised in Figure 8.1.

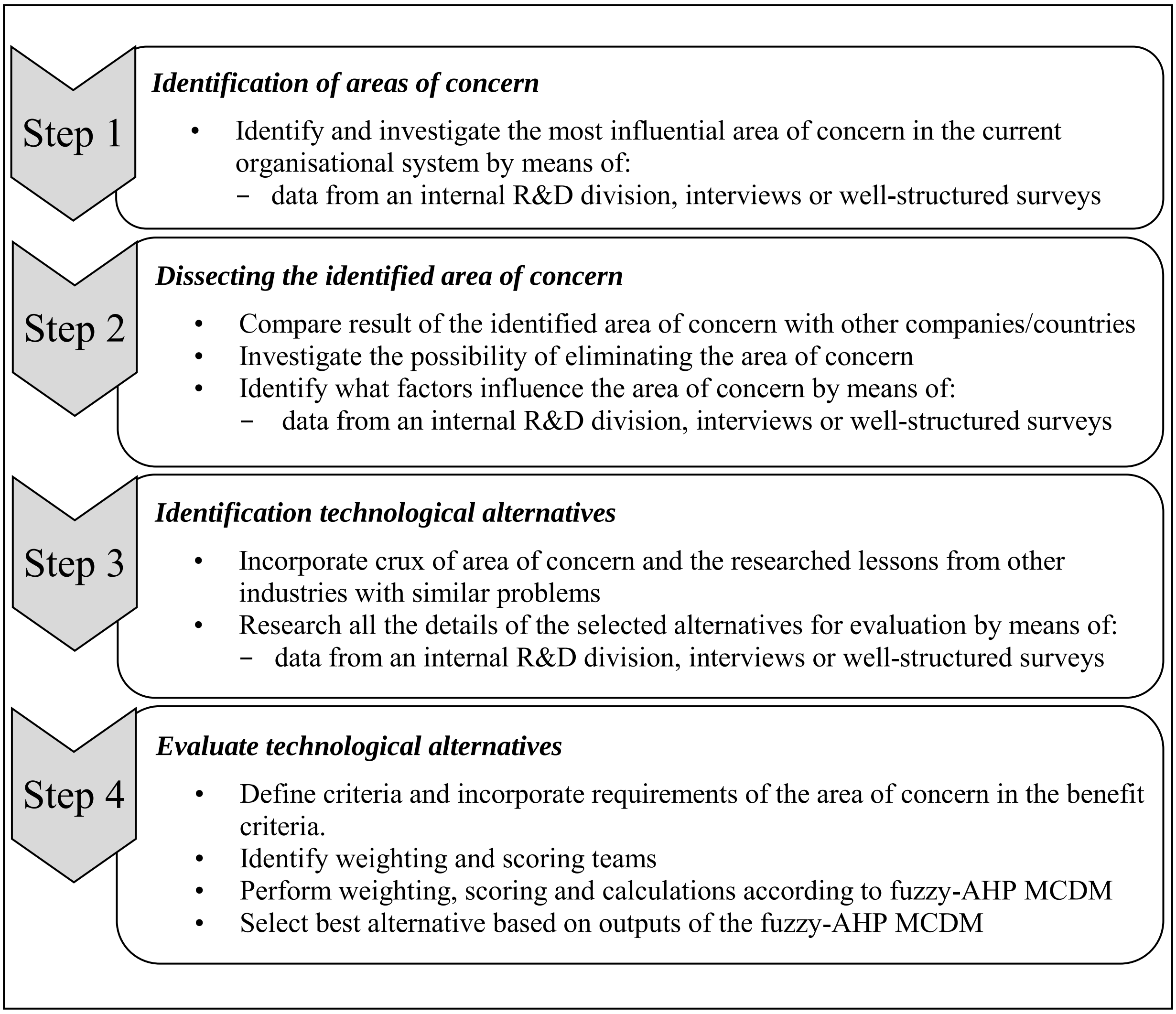

Figure 8.1 - Summarised process assisting technological investment decisions in construction

Step1- Identification of areas of concern:

The first step of the process is supported by literature which stated that the identification and solving of existing areas of concern are part of the first steps to improvement.

The core of correctly identifying an area of concern is to have enough data that is accurate. Whether data is obtained from global indexes, published surveys or company performance reports, the identified concern should be supported by sufficient data. If the identification of a concern is done for a specific company, a good understanding of the company strategy is needed so that the data obtained can be understood and be seen within a specific context.

The automotive manufacturing industry focuses on innovation within their dedicated R&D divisions and this is how these manufacturing companies ensure long-term competitiveness. These R&D divisions constantly provide management with information about possible concerns and solutions to these concerns.

The lack of dedicated R&D divisions can force the researcher to gather information by other means. The identification of areas of concern can, however, be done by means of prior research followed by interviews and the analyses of well-constructed surveys.

Step 2 -Dissecting the identified area of concern:

The next step of the process is to dissect the area of concern that was identified in Step 1. This dissection involves identifying how the data derived from Step 1 compares to other countries or companies. It should then be considered if the problematic area could be eliminated and how this can be done. If the area of concern is something that is not removable, then it should be identified what factors influence the area of concern and how these problematic factors can be improved on. Having a sound understanding of the problem can assist the identification of possible problematic areas and help to determine what is needed for improvement.

Step 3 –Identify technological alternatives:

In this step of the process, the findings of Step 2 have to be considered to determine the crux of the area of concern. Based on the crux of the concern, examples of similar problems in other industries should be researched where possible. This research can be done by an internal R&D division within a company or by the individual responsible for the decision making. This gives the researcher the opportunity to find the crux of the problem faced and also to learn from other industries and to identify what solutions the other industries used to overcome similar problems.

By identifying the crux of the problem and combining it with lessons learned from other industries, the solution alternatives will be more easily selected due to the narrowed scope of alternatives. Once the alternatives are selected for evaluation, full details regarding the performance and specifications of the alternatives need to be researched by either the internal R&D or by the individual.

Step 4 –Evaluate technological alternatives:

The fourth and final step involves the evaluation of solution alternatives and it is where the actual decision making is done. To make an evaluation, the effects of the investment need to be quantified in order to determine how the costs compare to the benefits of the investment. Section 8.3.1.5 explains exactly how this quantifying procedure works in detail.

The evaluation process is done by incorporating multiple criteria and the opinions of different stakeholders in a fuzzy-AHP MCDM. The first steps consist of selecting the criteria and incorporating the details of the specific problem in the benefit criteria. The next step of the evaluation is to assign weights by using a weighting team consisting of various stakeholders on different levels of management. The weighting is followed by scoring the performance of each alternative with regards to the different criteria. This is done by the scoring team who also consist of different stakeholders as in the case of the weighting team.

The weighting team assigns the weights according to company values and strategy. The scoring of the alternatives can only be accurate if enough information is given to the scoring team with regards to the performance and specifications of each alternative. This can be provided by the supplier or salesperson of each alternative or it can be researched to find out how these alternatives performed in other applications.

The weighting and scoring is done by using linguistic terms that translate into fuzzy numbers. These fuzzy numbers express the degree of the team members' feelings when weighting criteria or scoring alternatives. This is safer and easier to use because it was stated in this research that it is dangerous to assign crisp values when working with technology investments, and they therefore advise that fuzzy numbers be used.

The fuzzy logic approach, complex criteria structure, and a process of weighting and scoring are used in a specific fuzzy-AHP MCDM that determines the best alternative. This model utilizes the scores and weights of the team members, equations and matrix calculations together with translation tables to determine the best alternative.

8.3 Discussion of research objectives

In this section, the research objectives initially posed in Chapter 1 are re-examined in light of the results of the research conducted in the previous chapters. The research objectives included six research questions and a hypothesis that needed to be tested. The findings of chapters 4 to chapter 6 address the research questions in various ways and provide sound solutions and insights to the questions. The hypothesis is discussed in this section and makes use of three steps to test it. These steps include stating the requirements of the hypothesis, providing supporting findings and lastly justification of the outcome of the test.

8.3.1 Research questions:

In this section the six questions stated in the beginning of the research will be discussed, making reference to the findings of the various elements of the current research study.

8.3.1.1 Are there any generic areas of concern in the different divisions of civil engineering construction?

Before attempting to answer this question, the term 'generic' has to be clearly defined in order to fully understand the context of this discussion. According to Oxford dictionaries the term generic is an adjective that gives the noun a characteristic of relating to collective group and is therefore not specific but common (Oxford University Press, 2006). In the context of the discussion regarding areas of concern in construction, this means that a generic area of concern is an area of concern that is related to the construction industry as a whole and therefore not specific to one division in the construction industry.

Assaf and Al-Hejji (2006) conducted a large survey to identify the areas of concern in construction. The survey conducted by Assaf and Al-Hejji (2006) was sent out to many different industry representatives in different divisions of civil engineering construction in Saudi Arabia. In their study they found that there are indeed areas of concern as identified by the respondents. Given that the fields of work of the respondents were different, and that these were areas of concern that were identified to be present by most of them, make those areas of concern generic. They are, however, only generic to the scope of that investigation and it can be argued that these areas of concern are only generic in construction in Saudi Arabia. For this reason the South African perspective will now be discussed.

The list that was created by Assaf and Al-Hejji (2006) was used and the top 49 issues had been placed on a list and given to specific managers to rate. As described in section 3.1, these managers were chosen specifically due to their experience in divisions of civil engineering construction in South Africa. The different division of civil engineering construction was defined in section 2.1.4 and the definition was based on various literature references.

Interviews were conducted with these managers and the data of the ranked lists of areas of concern were analysed. It was seen that the same deductions could be made from the interviews and data of lists from these managers in South Africa than the results of Assaf and Al-Hejji (2006). The interviewees all acknowledged that all of the items in the list of areas of concern exist in their projects. None of the interviewees indicated that the areas on the list are not present in their projects and hence rated each area of concern with regards to the impact the concerns has on their projects.

Another step was taken to identify the impacts of the areas of concern and a larger group of experienced managers all of who attended the 2012 CMP was asked to rank a shorter list of concerns. All 38 respondents indicated that the areas of concern on the shortened list have a noticeable impact on various areas of the projects they have been exposed to.

Summarised answer to the question:

It can, therefore, be deduced that there are indeed generic areas of concern in civil construction industry. This answer is supported by the acknowledgement of the existence of specific areas of concern by various industry representatives during interviews and surveys.

8.3.1.2 What is the most influential area of concern in the South African construction industry?

During the research of the South African construction industry it was found that it is a very big and complex industry. By investigating the different divisions of civil engineering construction, it could be seen that the different divisions deal with construction in a unique way.

The previous question showed, based on literature, interviews and surveys, that there are in fact generic areas of concern in construction. However, it was seen that even though most construction companies have a generic list of concerns, not all companies or even divisions within a company rate the impact of these areas of concern equally. A good example of this phenomenon was seen in the varying ratings the interviewees gave for the impact of one area of concern within different divisions of the same company.

Despite the varying results, the inputs of the interviewees were still utilized to identify which of the areas of concern have the biggest average impact. The average impacts of the areas of concern were calculated by averaging all of the interviewees' ratings. Only a number of the areas of concern were selected, based on the highest average impact, for further investigation. This was seen as a screening procedure to eliminate some areas of concern that are regarded less influential.

The second step towards identifying the most influential area of concern was to get expert opinions from highly experienced industry representatives. The 2012 CMP delegates were used to give their expert opinions about what they regard as the most influential area of concern in South African construction.

The survey containing the screened list of areas of concern was filled in and it was still seen that there are areas of concern that have bigger impacts on construction projects than others. These areas of concern were particularly important in this research in order to narrow down the focus of the investigation. The delegates of the 2012 CMP, who all work for South African construction companies, identified low labour productivity of labourers as the most influential area of concern. This result could be justified by the introduction of the EPW in 2004 and the high amount of labour that is to be used in South African construction projects. A further validation could come from the fact that a large percentage of a construction project's costs and money is spent on labour related items. Therefore if labour is prominent in South African construction and has areas that need improvement, labour can be a highly influential area of concern.

Summarised answer to the question:
Low labour productivity.

8.3.1.3 What aspects of this area of concern can be improved on?
The area of concern that was identified by the 2012 CMP delegates to be the most influential was low labour productivity, and this area of concern was therefore chosen for further investigation.

In Chapter 4 labour productivity was discussed and various factors that influence productivity were identified. A *productivity improvement system* was analysed and areas of this system that could be improved on, were identified. These areas included inputs to the system, factors influencing productivity, measuring productivity, comparing actual to estimated productivity and taking action with feedback. Due to the fact that technology is proposed as the solution, it could not be identified exactly what inputs needed to be included in the productivity system because the feasibility of the technology still has to be proven. However, it was found that there are many factors influencing labour productivity and they can be grouped in three categories. These categories are labour effectiveness, management practices and material timeliness. All three of these categories have a large number of areas that can be improved on and can be seen in section 5.1.2.

Each of the different methods of measuring productivity had areas that could be improved on and each posed different problems. It was realised that the problems with regards to measuring productivity are method specific and just as the method of measuring productivity can differ on every project, so can the problematic areas with regards to productivity measurement.

If the amount and the correctness of data regarding productivity were to be increased, it could have beneficial effects for productivity on site. Data capturing was, therefore, also identified as an area where the productivity improvement could be improved on. Various literature references identified how technology can assist many of these areas in the *productivity improvement system* and giving feedback is another one of these areas. If the feedback of productivity is understandable it can contribute to the motivation of the workforce and further improve productivity.

Another area that could be improved on regarding productivity of labourers is to focus on eliminating productivity inhibitors. Management related inhibitors are the most susceptible to change and 50% of all inhibitors are related to management. The most important productivity inhibitors that management can improve on are the lack of managing overtime, de-motivators and productivity measurements.

Summarised answer to the question:

There are many aspects of the productivity improvement system that can be improved on which are:

- Input to the productivity improvement system
- Factors influencing productivity (management practices, labour effectiveness, material timeliness)
- Measuring productivity (better and more data)
- Comparing actual and estimated productivity
- Feedback to labourers, managers and other stakeholders interested in labour productivity

8.3.1.4 What technology can be used to address the area of concern?

In Chapter 6 it was shown that the identification of technology was done based on the learning from other industries. This was done by considering the findings of Chapter 4 and Chapter 5 and determining the crux of the labour productivity problem. The crux of the problem lay in two valuable realisations, the first of which is that increased monitoring of labourers was needed to improve the quality and amount of usable data for productivity management. Another realisation was that the behaviour of the labourers must be optimised into completing tasks more efficiently.

These two realisations were taken into consideration with similar problems in other industries and this lead to the industries of sport and traffic control. Traffic lights and traffic cameras did, to some extent, manage to dictate and optimise motorists' behaviour. The management of professional sports teams is an example of another industry that managed to improve the behaviour of players on a field by closely monitoring their behaviour and movements. The technologies used in these industries were wireless tracking and visual analysis.

Visual analysis and image processing is done by analysing video material or a sequence of frames and estimating movements based on the different position of the resource. This analysis can be done manually or automatically and research is currently done to improve the automated video tracking of resources. Wireless tracking has many alternative methods of tracking such as, GPS, Wi-Fi, RFID, Bluetooth and UWB. UWB proved to be the best performing wireless tracking method for construction sites and works on the principle of attaching a transmitter on the resource that is picked up by the local receivers. These receivers and accompanying software can then determine the position, movement and speed of the resource in a 3D context.

Investigation into these groups of alternatives showed that the technology can have the following advantages:

- Accurate 3D tracking of resources behaviour such as position, speed and direction of movement
- Provides data that can be used to monitor and manage work task schedules
- Improved productivity measurements
- Real time data that can be used for improved safety on site
- Improved monitoring of resources even in buildings and underground areas

Summarised answer to the question:
By improved monitoring and capturing more data with either one of the above mentioned groups of alternatives, labourers' behaviour could be improved and better data could be acquired for improved productivity management.

8.3.1.5 How will the effects of the technology be quantified in terms of cost versus benefit?
Decisions on whether or not to invest in a technological alternative should be done based on a feasibility study. This often includes the evaluation of the relationship between the costs of the investment versus the benefit it could provide. However, when an investment is proposed for the improvement of an area of concern, it makes sense to include criteria to evaluate whether the benefits sought after with this investment will be achieved. In section 7.2 five categories of criteria were identified namely external -, internal -, risk -, cost - and benefit criteria. Together these categories form the criteria structure for the evaluation.

The external criteria is included in the criteria structure to evaluate alternatives in terms of the benefits it can provide regarding allying with other partners and how other competitors will react to the decision. The internal criteria were included to evaluate the ability of the alternatives to integrate with current company systems and how the users will accept the alternatives. The risk criteria are included so that the probability of achieving the desired outcome can be evaluated. The cost criteria evaluate the financial impact of each alternative. The benefit criteria were specifically included to assess the alternatives' ability to satisfy the needs of solving the area of concern identified.

Many technology investments fail due to the lack of compliance with the needs of all parties affected by the investment (Chou, et al., 2006). User rejection is one of the main examples of this phenomenon and for this reason the evaluation of the possible investment includes two teams that assist with the decision making (Chou, et al., 2006). Both of these teams include stakeholders that range from the user to management and often include a consultant or expert in the field.

The first team is the weighting team, and their task is to assign weights to the criteria. This is done by considering the company strategy and how important some of the criteria are to the company. The second team is the scoring team and their job is to evaluate how well an alternative performs against each of the criteria. For the scoring team to evaluate the performance of the alternative, the specifications of the alternatives are needed to fully understand what each alternative has to offer when used. This is an ideal task for an in-house R&D division, especially because they could investigate the alternative based on the specific needs of the company.

It is challenging to give crisp values for the weight of a criterion or to assign an accurate score for the performance of an alternative. Besides being challenging, assigning crisp values to these aspects are dangerous when working with technology investments (Chou, et al., 2006). For this reason a fuzzy logic approach was used so that the team members can use linguistic terms to describe their choices. These linguistic terms were translated into fuzzy numbers which represent a range of values rather than a crisp value.

Together with the teams of stakeholders, fuzzy logic approach and the complex criteria structure, a specific fuzzy multi criteria decision model (FMCDM) was created for decision making. Although the model was specifically aimed at making decisions with regards to technology to improve labour productivity, the criteria can be changed so that it evaluates other problems.

Summarised answer to the question:

A FMCDM model not only provides a structured way to compare the cost versus benefit of investments but manages to provide the following additional benefits:

- Incorporates the opinions of the stakeholders in every level of the business
- Integrate risk, benefit and cost criteria into one model
- Has the flexibility to change with regards to weights given to criteria
- Combines quantitative and qualitative decision making into one model
- Is easy to use and saves time

8.3.1.6 Can technology be used to improve a problem solving process of construction companies?

The term improve is a relative term and in the light of the varying business strategies of different companies and the legislation of different countries, improvement can be perceived differently. However, given the details in Chapter 5 it could be seen that the problem solving process of this research was the productivity improvement system. It was seen in the discussions in Chapter 5 that there are various areas of this system that can be improved with the use of technology. The term improve is used in this context to refer to the time savings of utilising computer software to do productivity calculations (Basant & Fikkert, 1993).

According to Basant and Fikkert (1993) many benefits are experienced with technology investments in construction and other industries. They stated that the rates of return with regards to R&D and technology are high and are applicable to various areas of application. These statements are supported by the researchers of wireless tracking – and visual analysis technology that claimed to have experienced major benefits from the use of technology in time savings, resource management, theft and safety aspects (Jiang, et al., 2010) (Yuan & Sun, 2010) (Teizer, et al., 2008).

Not only is it stated by literature that technology has many areas of application, this research study identified various areas where technology could aid the productivity improvement system. Two examples which included wireless tracking and visual analysis has also proved to improve productivity on site and assists in data capturing for productivity measurement.

Summarised answer to the question:

Based on the literature of Basant and Fikkert (1993) and the identified areas of application for technology in this research study it can be stated that technology can improve a problem solving process of construction companies.

8.3.2 Research hypothesis:

In this section the hypothesis stated in the beginning of this research thesis will be discussed. This discussion will make reference to other sections within the document that have covered some of the areas of the discussions. The first step of proving the hypothesis will be to clarify what the requirements are so that the hypothesis can be tested. Secondly findings on the requirements of the hypothesis will be given after which the justification of why the hypothesis is true or false will be explained.

8.3.2.1 A generic and flexible process can be formulated to assist construction companies in making decisions with regards to technological investments

8.3.2.1.1 Requirements of hypothesis:

The terms generic and flexible will be defined and explained in this context to understand the hypothesis's value. Just as described in section 8.1.1.1 generic is an adjective that gives the noun a characteristic of relating to collective group and is therefore not specific but common (Oxford University Press, 2006). Flexible is defined by the Oxford Thesaurus of English as an adjective that gives a noun the property to adapt, change or adjust. In the context of this research a generic and flexible process refers to the following:

1.) The process is not only applicable to a specific area within construction but usable in more than one division, company or even country.

2.) The process is able to be adapted to changes that occur in business strategies, company employees, criteria or area of concern.

8.3.2.1.2 Supporting findings

The supporting findings that explain the working of the proposed process is described in section 7.4, section 8.1 and section 8.2. In all these sections it is mentioned that the process used can be used for various areas of concern, various team members and different criteria. It is stated that the process is systematic, understandable and that it incorporates different stakeholders during the process of decision making.

8.3.2.1.3 Justification

The first requirement to prove this hypothesis is that the process should be generic, and that it should be able to be used by various divisions of construction in different companies and even in different countries. The proposed process is able to be used in this regard, because the research during the identification and dissection of areas of concern as identifying solutions can be done for specific contexts. Furthermore the evaluation of the alternatives is done by teams of which the members can be chosen and changed. The findings of this research only highlighted the value of specific types of representatives and each division can choose their own appropriate representatives in their teams.

The second requirement of the hypothesis is that the process must be able to change when business strategies, employees, criteria or area of concern changes. This proposed model is able to adapt to any of these changes because of the following reasons:

- Business strategies are reflected by the weighting of the criteria and these weights can be changed with each new decision
- If employees change the team members may not necessarily have to change but if, for some reason, a team member resigns, a replacement representative can be incorporated for the new decision.
- If the area of concern changes, which is highly likely if the company wants to improve more concerns, the benefit criteria can be altered according to the new benefit requirements of the alternatives

Based on the above justification, the two requirements of the hypothesis is satisfied and the hypothesis is proven to be true.

8.4 Advantages and shortcomings of the proposed solution to the problem statement

From this research study a four step process, explained in section 8.2, is proposed which could be used in construction to assist technological investment decisions. This process is therefore a solution to the problem statement presented in section 1.2. The advantages and shortcomings of this process will now be considered.

8.4.1 Advantages of proposed process

As explained in section 8.3.2, this process is generic and flexible. This means that the process is not only applicable to a specific area within construction but usable in more than one division, company or even country. The process is also able to adapt to changes that occur in business strategies, company employees, criteria or area of concern.

This process is therefore sustainable and can be used and adapted in fast changing environments. Besides being flexible and generic the process can be consistent because it incorporates elements such as the weighting of criteria which incorporates the business strategy and this can be left unchanged for future decisions. The process is structured in manageable and understandable steps which makes the decision making process an incremental solution process. With the incorporation of software that could do the calculations explained in section 8.4, this process can be further simplified.

The process and the research conducted to establish this process has provided the benefits in each step of the process. The steps of the process will be used to organise these benefits and can be seen below:

Step1- Identification of area of concern:

- The data regarding the impact of the various areas of concern has exceptional value to the construction industry due to the amount of respondents and the experience these respondents has.
- The survey templates used in the surveys of this research can be used for other topics listed in the recommendations for further studies in Chapter 10.

Step 2- Dissecting the area of concern:

- The dissection of labour productivity provided in-depth information on techniques used to measure productivity as well as the factor influencing productivity. This can be used as a guide for implementation in the construction industry.

Step 3- Identification of technological alternatives:

- Two groups of technology were identified as possible solution alternatives, and these technologies are currently being researched to further develop the technology. Research has however already provided data where the application of these groups of technologies has provided benefits with regards to productivity improvement on construction sites.

Step 4 – Evaluation of technological alternatives:

- The criteria structure included in the evaluation model is specifically tailored for technology investments.
- The benefit criteria incorporates labour productivity's needs for improvement.
- The criteria structure incorporates business strategies by utilising the step of weighting the importance of the criteria. The criteria structure is also flexible enough to support the logical incrementalism decision making approach used by contractors in South Africa.
- The model involves all levels of stakeholders and for this reason there is no need to separate strategic, tactical or operational decisions.
- The evaluation model incorporates Fuzzy logic which is an improvement on the AHP method and its shortcomings.
- The mathematical domain of the inputs from the weighting and scoring teams makes the model susceptible for implementation on software packages.
- The model’s steps for implementation are incremental and break down the overwhelming thoughts of the DM into structured steps.

8.4.2 Shortcomings of proposed process

The proposed process has shortcomings, especially when surveys and interviews are used to obtain data. A shortcoming of obtaining data through surveys and interviews is that there can be sampling limitations because of the difficulty in receiving input from every representative in the industry. The survey and its results of this research study were regarded as valuable contributions, especially given the

significant experience and high management positions of the respondents. However, the result cannot be stated to be the perception of all South African construction companies.
Based on the size of the South African construction industry and the difficulty of standardizing areas of concern from different companies and divisions, it is difficult to identify what the most influential area of concern is for all. It can however be stated that the probability is high that low productivity of labourers is a major area of concern in many construction companies in South Africa.

When surveys and interviews are implemented within a company the sample size is smaller and the company strategy is the same, as opposed to the survey in this thesis where respondents were from different companies. The probability of receiving the opinions of every representative in a single company is therefore higher and the sampling limitation could be mitigated, because the survey will reflect the true opinion and view of the company. In this research only 38 respondents were asked to represent the opinion of the South African construction industry. The opinion received might not be exactly the same as the opinion derived if every representative of the industry was surveyed.

A further limitation of this process is that if the process would to be implemented by a person never exposed to this process, the calculations in the evaluation process could take some time. If computer software were to be developed for this purpose this shortcoming of the process would be addressed.

8.5 Conclusion

This chapter presented the findings of the research and the synthesis of the process that was proposed. The research questions were answered and a hypothesis was tested. The findings of the study were used to justify the acceptance of the hypothesis.

CHAPTER 9

Conclusion

In this chapter the research study is summarised and it is summarized how all the chapters have contributed to the initial problem statement.

The literature study that was done in Chapter 2 showed that the civil construction industry is one of the biggest and most influential industries worldwide but lags behind in developments in technology-aided construction. A comparison was made between the construction and the manufacturing industries and it was found that manufacturing utilised R&D to a greater extent than construction. Research on the development of technology and the usage thereof showed that South Africa is behind when compared to other counterparts.

Given that focus is now being put on technological investment and infrastructure development, it was identified to investigate ways in which construction companies could be aided with making difficult technology investment decisions. The first step of improvement was identified to be the elimination or improvement of areas of concern. For this reason Chapter 3 presented the interviews, surveys and analyses used to identify the most influential area of concern in South African construction. Low labour productivity had been identified as the most influential area of concern and was selected as the concern that needs to be solved in this research study. This concern was used as a case study to introduce and calibrate a process which could assist technology investment decisions.

In Chapter 4 labour productivity was dissected to provide a broad foundation on the key elements of the concern and to identify possible areas that could be improved. Chapter 5 highlighted these areas of improvement by using the productivity improvement system and the investigation of Chapter 4.

Chapter 6 utilised the findings of Chapter 5 and incorporated the lessons learned from other industries to identify technological solution alternatives that could improve the areas identified in Chapter 5. Wireless technology and visual analysis were identified as the two groups of technology that could provide solutions to the problems imbedded in the labour productivity concern.

Chapter 7 incorporated the evaluation process that should be executed in order to make an informed decision regarding the investment. A model was used to incorporate the opinions of different stakeholders, multiple criteria, business strategies and the benefits required to solve the area of concern. Research showed that fuzzy-analytical hierarchy process multi criteria decision models have been used with success to incorporate these elements in one decision making model. The model utilises criteria specifically tailored for technology investments and have groups of criteria it incorporates. The criteria was grouped into external -, internal -, risk -, cost and benefit criteria. Together these criteria form the basis on which the evaluations of alternatives are made.

Chapter 8 presented the findings of the research and showed that the method used in this research represented a process that could assist technological investment decisions in construction. After answering the research questions and utilising those discussions to prove the hypothesis it can be stated that a generic and flexible process was proposed that can assist technological investment decisions that aim to solve areas concern. The advantages and disadvantages of the process were identified and were also discussed in Chapter 8.

The validated process consists of:

- Step1- Identification of areas of concern
- Step 2 -Dissecting the identified area of concern
- Step 3 –Identifying technological alternatives
- Step 4 –Evaluating technological alternatives

This process can be used by construction managers in companies experiencing areas of concern. The nature of the process is so that it can be used in different divisions or companies in the construction sector.

CHAPTER 10

Recommendations for further study

This research study was performed over a two year period and only allowed the investigation of a limited number of areas. In this section a few areas that had been seen to be relevant, but were not investigated, will be discussed and are recommended for further research.

10.1 Labour statistics in different projects/activities

In this research study it was found that the labour time and cost allowable are high in construction projects. It was, however, not investigated if there are trends with regard to the number of labourers of different types of construction projects. It is therefore suggested that further investigation is done to identify if there are different amounts, durations and prices of labour on different projects and if these statistics should rather be calculated on activity level. If these statistics can be related to specific activities then specific projects should be investigated in terms of trend of these activities.

10.2 What does a R&D division comprise of?

In this research study emphasis was placed on the role R&D has played in manufacturing and it is proposed that R&D divisions should exist in construction companies. It was, however, not identified what these R&D divisions should comprise of. The specific type of employees, strategies and size of the divisions are unclear. Further investigation into what is done in the manufacturing industry with regards to these elements of a R&D division should be identified so that construction companies can start implementing these R&D divisions.

10.3 Boards and institution for R&D in construction

During the investigation in section 2.2.4.2 of this research, the boards and institutions in South African civil engineering, was seen to be lack in focus on technological innovation and R&D. The possibility of establishing a board or institution that focuses on these topics would be needed, especially if it was compared to the manufacturing industry. It was not investigated how manufacturing implements R&D on this level, and this investigation could shed light on the benefits of such a board.

10.4 Importance of cost, time, quality and risk

In Chapter 3, an assumption was made that the weights of time, cost, quality and risk are taken as equal in the calculations determining the influence of a specific area of concern. This assumption was made due to the difficulty of investigating the importance of these elements for different divisions, companies and countries in the given time frame. Further research can be done to determine the importance of these elements and how they are interlinked with, or inter-dependant on each other. Research could be done to determine if these elements have different importance within different types of construction projects. The topic of business strategies and companies is a further investigation that is seen as elements that could also influence the importance of these four elements.

10.5 Investigation of different areas of concern

The purpose of Chapter 3 was to narrow down the investigation so that only one area of concern is investigated. This was done due to time constraints and because the most influential area of concern was identified to add value to this research study. As mentioned earlier in section 8.4.2, the chosen area of concern may not be the most influential area of concern in other companies. For this reason it would be valuable to investigate other areas of concern that were identified as influential in Chapter 3. This research study only investigated the low labour productivity area of concern and investigating other identified areas of concern could prove valuable to other companies and the construction industry.

In the case of the South African construction industry, the issue of current legislation, with regards to the EPWP and labour could be investigated. This could provide insight into the short and long-term effects this program has on the South African construction industry and its companies.

10.6 Measuring productivity

In Chapter 4, various productivity measuring techniques were identified and explained. This research study did, however, not investigate the suitability of specific methods for specific construction projects, -activities and - companies. Further studies on whether there is one specific technique that is the best can be investigated or whether specific methods should be used for specific labour tasks. The suitability of the measuring technique should incorporate the way in which data is being captured and whether the proposed technologies will have an influence in the suitability of the techniques.

10.7 Privacy legislation

The proposed technological alternatives may invade the rights of the labourers in terms of privacy. This investigation could have a major influence on whether these solutions can be used. Further investigation is therefore advised to shed light on this matter.

10.8 Important productivity indicators

In Chapter 5 it was identified that the feedback of productivity measurements should be understandable and usable to increase motivation. Further investigation should be done to determine which indicators are important to measure and provide feedback on. A method for presenting productivity performance data should be investigated to identify the best suited way of presenting the data as motivational feedback.

10.9 Practical implications of implementing alternatives

This research project identified two groups of technological alternatives as solutions to the low labour productivity problem, i.e. wireless tracking and visual analysis. It was not investigated what the implications would be for implementing these alternatives. Investigation into the cost, availability and installation difficulty should be investigated to provide more information regarding decision making between these alternatives.

10.10 User interface for implementation of the alternative evaluation process

A process was identified in this research study, which included an evaluation step that requires a series of calculations to be done. These calculations are performed after weighting of criteria and scoring of alternatives are done. The evaluation step can be simplified by investigating the possibility of developing a software user interface that will structure these tasks so that the user experience is improved. This study can focus on user friendliness and the restrictions of self-assessments and the interpretation of the results obtained from this process.

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Appendix A – Sample list of areas of concern identified in literature

Rank (1-10)	Concern #	Description of area of concern	Source
	1	Difficulties in financing project by contractor	Contractor
	2	Conflicts in sub-contractors schedule in execution of project	Contractor
	3	Rework due to errors during construction	Contractor
	4	Conflicts b/w contractor and other parties (consultant and owner)	Contractor
	5	Poor site management and supervision by contractor	Contractor
	6	Poor communication and coordination by contractor with other parties	Contractor
	7	Ineffective planning and scheduling of project by contractor	Contractor
	8	Improper construction methods implemented by contractor	Contractor
	9	Delays in sub-contractors work	Contractor
	10	Inadequate contractor's work	Contractor
	11	Frequent change of sub-contractors because of their inefficient work	Contractor
	12	Poor qualification of the contractor's technical staff	Contractor
	13	Delay in site mobilization	Contractor
	14	Delay in performing inspection and testing by consultant	Consultant
	15	Delay in approving major changes in the scope of work by consultant	Consultant
	16	Inflexibility (rigidity) of consultant	Consultant
	17	Poor communication/coordination between consultant and other parties	Consultant
	18	Late in reviewing and approving design documents by consultant	Consultant
	19	Conflicts between consultant and design engineer	Consultant
	20	Inadequate experience of consultant	Consultant
	21	Shortage of construction materials in market	Materials
	22	Changes in material types and specifications during construction	Materials
	23	Delay in material delivery	Materials
	24	Damage of sorted material while they are needed urgently	Materials
	25	Delay in manufacturing special building materials	Materials
	26	Late procurement of materials	Materials
	27	Late in selection of finishing materials due to availability of many types in market	Materials
	28	Equipment breakdowns	Equipment
	29	Shortage of equipment	Equipment
	30	Low level of equipment-operator's skill	Equipment
	31	Low productivity and efficiency of equipment	Equipment
	32	Lack of high-technology mechanical equipment	Equipment
	33	Shortage of labourers	Labourers
	34	Unqualified workforce	Labourers
	35	Nationality of labourers	Labourers
	36	Low productivity level of labourers	Labourers
	37	Personal conflicts among labourers	Labourers
	38	Effects of subsurface conditions (e.g., soil, high water table, etc.)	External
	39	Delay in obtaining permits from municipality	External
	40	Hot weather effect on construction activities	External
	41	Rain effect on construction activities	External
	42	Unavailability of utilities in site (such as, water, electricity, telephone, etc.)	External
	43	Effect of social and cultural factors	External
	44	Traffic control and restriction at job site	External
	45	Accidents during construction	External
	46	Differing site (ground) conditions	External
	47	Changes in government regulations and laws	External
	48	Delay in providing services from utilities (such as water, electricity)	External
	49	Delay in performing final inspection and certification by a third party	External

Appendix B – Initial ranking of areas of concern

Rank #	Concern #	Area of concern description (O)	Source	Rating (R)				Ave. Rating (R_A)	Std. Dev.
				Structural (M_1)	Water (M_2)	Transport (M_3)	Geotech. (M_4)		
1	15	Delay in approving major changes in the scope of work by consultant	Consultant	4	5	7	10	6.5	2.64
2	18	Late in reviewing and approving design documents by consultant	Consultant	4	5	6	9	6	2.16
3	36	Low productivity level of labourers	Labour	4	8	8	4	6	2.30
4	7	Ineffective planning and scheduling of project by contractor	Contractor	2	5	5	10	5.5	3.31
5	34	Unqualified workforce	Labour	2	7	8	5	5.5	2.64
6	9	Delays in sub-contractors work	Contractor	4	7	5	5	5.25	1.25
7	20	Inadequate experience of consultant	Consultant	2	5	6	8	5.25	2.5
8	28	Equipment breakdowns	Equipment	4	4	5	8	5.25	1.89
9	45	Accidents during construction	External	4	6	5	5	5	0.81
10	4	Conflicts b/w contractor and other parties (consultant and owner)	Contractor	4	3	8	5	5	2.16
11	16	Inflexibility (rigidity) of consultant	Consultant	2	7	6	5	5	2.16
12	25	Delay in manufacturing special building materials	Materials	4	5	3	8	5	2.16
13	3	Rework due to errors during construction	Contractor	4	3	5	7	4.75	1.70
14	11	Frequent change of sub-contractors because of their inefficient work	Contractor	1	3	5	10	4.75	3.86
15	26	Late procurement of materials	Materials	4	4	4	7	4.75	1.5
16	5	Poor site management and supervision by contractor	Contractor	2	4	5	7	4.5	2.08
17	10	Inadequate contractor's work	Contractor	2	3	6	7	4.5	2.38
18	19	Conflicts between consultant and design engineer	Consultant	4	2	4	8	4.5	2.51
19	6	Poor communication and coordination by contractor with other parties	Contractor	2	2	6	7	4.25	2.62
20	12	Poor qualification of the contractor's technical staff	Contractor	2	2	4	9	4.25	3.30
21	13	Delay in site mobilization	Contractor	2	2	4	9	4.25	3.30

Rank #	Concern #	Area of concern description (O)	Source	Rating (R)				Ave. Rating (R_A)	Std. Dev.
				Structural (M_1)	Water (M_2)	Transport (M_3)	Geotech. (M_4)		
22	17	Poor communication/coordination between consultant and other parties	Consultant	2	2	7	6	4.25	2.62
23	22	Changes in material types and specifications during construction	Materials	4	3	3	7	4.25	1.89
24	23	Delay in material delivery	Materials	2	5	3	7	4.25	2.21
25	29	Shortage of equipment	Equipment	2	2	5	8	4.25	2.87
26	39	Delay in obtaining permits from municipality	External	2	1	4	10	4.25	4.03
27	2	Conflicts in sub-contractors schedule in execution of project	Contractor	2	4	4	6	4	1.63
28	8	Improper construction methods implemented by contractor	Contractor	2	2	5	7	4	2.44
29	30	Low level of equipment-operator's skill	Equipment	2	4	5	5	4	1.41
30	31	Low productivity and efficiency of equipment	Equipment	4	2	5	5	4	1.41
31	49	Delay in performing final inspection and certification by a third party	External	2	2	7	5	4	2.44
32	14	Delay in performing inspection and testing by consultant	Consultant	2	2	6	5	3.75	2.06
33	24	Damage of sorted material while they are needed urgently	Materials	4	3	3	5	3.75	0.95
34	46	Differing site (ground) conditions	External	2	7	4	2	3.75	2.36
35	32	Lack of high-technology mechanical equipment	Equipment	4	2	3	5	3.5	1.29
36	37	Personal conflicts among labourers	Labour	1	6	3	4	3.5	2.08
37	38	Effects of subsurface conditions (e.g., soil, high water table, etc.)	External	2	7	3	2	3.5	2.38
38	40	Hot weather effect on construction activities	External	2	6	4	2	3.5	1.91
39	41	Rain effect on construction activities	External	2	6	4	2	3.5	1.91
40	21	Shortage of construction materials in market	Materials	1	3	3	6	3.25	2.06

Rank #	Concern #	Area of concern description (O)	Source	Rating (R)				Ave. Rating (R_A)	Std. Dev.
				Structural (M_1)	Water (M_2)	Transport (M_3)	Geotech. (M_4)		
41	27	Late in selection of finishing materials due to availability of many types in market	Materials	2	1	5	5	3.25	2.06
42	35	Nationality of labourers	Labour	1	7	3	2	3.25	2.62
43	48	Delay in providing services from utilities (such as water, electricity)	External	2	3	6	2	3.25	1.89
44	44	Traffic control and restriction at job site	External	2	3	4	3	3	0.81
45	1	Difficulties in financing project by contractor	Contractor	5	2	2	2	2.75	1.5
46	33	Shortage of labourers	Labour	2	1	3	5	2.75	1.70
47	42	Unavailability of utilities in site (such as, water, electricity, telephone, etc.)	External	2	3	4	2	2.75	0.95
48	43	Effect of social and cultural factors	External	1	2	5	3	2.75	1.70
49	47	Changes in government regulations and laws	External	2	1	6	2	2.75	2.21

Appendix C – Questionnaire

UNIVERSITEIT STELLENBOSCH UNIVERSITY

Research Input Form
Technology investments in construction (J.Kriel)
Thesis towards an MScEng in Construction Engineering and Management

FIRST HAND-OUT

SECTION 1: PERSONAL INFORMATION

Name and Surname:	
Employer/Company name:	
Job Title/Position: (e.g. Project manager, Engineer.)	
Company main service area: (e.g. Western-Cape, RSA)	
Company main business: (e.g. Buildings, Civils, Roads)	
Company CIDB rating:	
Project value range: (e.g. R1 million to R10 million)	
Years of experience:	
E-mail address:	

Personal information will not be disclosed in any part of the research. Your e-mail address is only to contact you for further questions if necessary.

SECTION 2: IMPACT OF CONSTRUCTION AREAS OF CONCERN

2.1 Rank the following construction areas of concern with a value (1-10) based on the degree of impact it has on the different areas.

1 = Low impact
10 = High impact

Issue	Impact Area					
	Time	Cost	Quality	Risk	Other	Other
Delay in approving major changes in the scope of work by consultant						
Late in reviewing and approving design documents by consultant						
Low productivity level of labourers						
Ineffective planning and scheduling of project by contractor						
Unqualified workforce						
Delays in sub-contractors work						
Inadequate experience of consultant						
Equipment breakdowns						
Accidents during construction						

SECOND HAND-OUT

SECTION 1: PERSONAL INFORMATION

Name and Surname:

SECTION 2: ANALYSING DIFFERENT AREAS OF CONCERN

2.1. ISSUE: UNQUALIFIED WORKFORCE

2.1.1 According to you what is the main cause of this issue? (e.g. education, lack of budget, awareness, communication etc.)

…………………..………………………………………………..…………………………………………

2.1.2 Have you /your company tried to solve or mitigate this issue? Select one box

- [ ] Yes extensively
- [ ] Yes
- [ ] Not really
- [ ] Not at all

2.1.3 How did you /your company try to solve or mitigate this issue? Select all applicable boxes

- [ ] Used Technology Please elaborate……………………..……………....……………………
- [ ] Used Management Please elaborate………………..........…………......…………....………
- [ ] Other Please elaborate……………………..…………………………………………
- [ ] NA

2.1.4 What was the reason why you/ your company chose the method in 2.1.3? Select all applicable boxes

- [ ] There was little time to decide what to do.
- [ ] It was the cheapest option
- [ ] Lack of knowledge on technology
- [ ] Lack of knowledge on management
- [ ] Lack of money to invest
- [ ] No resources (people) available
- [ ] No resources (technology) available
- [ ] Other Please elaborate……………..…………………………………………………………..

2.1.5 Are you aware of technology available to solve this problem? Select one box

- [ ] No
- [ ] Yes Please elaborate………....…………………………………………………………

2.1.6 Are you aware of companies using the technology in 2.1.5 to solve this problem? Select one box

☐ No
☐ Yes Please elaborate………...……………………...…………………………………….

2.1.7 Did the chosen action in 2.1.3 improve the issue? Select one box

☐ No
☐ Yes Please elaborate………...……………………………………………………………….
☐ NA

2.1.8 What were the effects of the chosen method in 2.1.3? Select all applicable boxes

Yes	No	Saved costs
Yes	No	Improved time
Yes	No	Reduced risk
Yes	No	Improved quality
Yes	No	Adoption of mitigation action by implementer was good
Yes	No	Adoption of mitigation action by receiver was good
Yes	No	Skill level of users was sufficient
Yes	No	Skill level of receivers was sufficient
Yes	No	Contracts and general law approved the action

☐ ***If other effects where present please elaborate on the blank space below***

2.2. ISSUE: INEFFECTIVE PLANNING AND SCHEDULING OF PROJECT BY CONTRACTOR

2.2.1 According to you what is the main cause of this issue? (e.g. education, lack of budget, awareness, communication etc.)

……………………..……………………………………………...……………………………………………

2.2.2 Have you /your company tried to solve or mitigate this issue? Select one box

- ☐ Yes extensively
- ☐ Yes
- ☐ Not really
- ☐ Not at all

2.2.3 How did you /your company try to solve or mitigate this issue? Select all applicable boxes

- ☐ Used Technology Please elaborate……………………..…………………………………
- ☐ Used Management Please elaborate……………………..…………………………………
- ☐ Other Please elaborate……………………..…………………………………
- ☐ NA

2.2.4 What was the reason why you/ your company chose the method in 2.1.3? Select all applicable

- ☐ There was little time to decide what to do.
- ☐ It was the cheapest option
- ☐ Lack of knowledge on technology
- ☐ Lack of knowledge on management
- ☐ Lack of money to invest
- ☐ No resources (people) available
- ☐ No resources (technology) available
- ☐ Other Please elaborate……………..………………………………………………………..

2.2.5 Are you aware of technology available to solve this problem? Select one box

- ☐ No
- ☐ Yes Please elaborate………...…………………………………………………………….

2.2.6 Are you aware of companies using the technology in 2.1.5 to solve this problem? Select 1 box

- ☐ No
- ☐ Yes Please elaborate………...…………………………………………………………….

2.2.7 Did the chosen action in 2.1.3 improve the issue? Select one box

- ☐ No
- ☐ Yes Please elaborate………...………………………………………………………….
- ☐ NA

2.2.8 What were the effects of the chosen method in 2.1.3? Select all applicable boxes

Yes	No	Saved costs
Yes	No	Improved time
Yes	No	Reduced risk
Yes	No	Improved quality
Yes	No	Adoption of mitigation action by implementer was good
Yes	No	Adoption of mitigation action by receiver was good
Yes	No	Skill level of users was sufficient
Yes	No	Skill level of receivers was sufficient
Yes	No	Contracts and general law approved the action

☐ ***If other effects where present please elaborate on the blank space below***

2.3. ISSUE: LOW PRODUCTIVITY LEVEL OF LABOURERS

2.3.1 According to you what is the main cause of this issue? (e.g. education, lack of budget, awareness, communication etc.)

……………………..………………………………………………..…………………………………………

2.3.2 Have you /your company tried to solve or mitigate this issue? Select one box

- ☐ Yes extensively
- ☐ Yes
- ☐ Not really
- ☐ Not at all

2.3.3 How did you /your company try to solve or mitigate this issue? Select all applicable boxes

- ☐ Used Technology Please elaborate……………………..…………………………………
- ☐ Used Management Please elaborate……………………..………………....……………
- ☐ Other Please elaborate……………………..…………………………………
- ☐ NA

2.3.4 What was the reason why you/ your company chose the method in 3.1.3? Select all applicable

- ☐ There was little time to decide what to do.
- ☐ It was the cheapest option
- ☐ Lack of knowledge on technology
- ☐ Lack of knowledge on management
- ☐ Lack of money to invest
- ☐ No resources (people) available
- ☐ No resources (technology) available
- ☐ Other Please elaborate……………..……………………………………………………..

2.3.5 Are you aware of technology available to solve this problem? Select one box

- ☐ No
- ☐ Yes Please elaborate………...…………………………………………………………

2.3.6 Are you aware of companies using the technology in 3.1.5 to solve this problem? Select one

☐ No
☐ Yes Please elaborate……….………………………………………………………….

2.3.7 Did the chosen action in 3.1.3 improve the issue? Select one box

☐ No
☐ Yes Please elaborate……….………………………………………………………….
☐ NA

2.3.8 What were the effects of the chosen method in 2.1.3? Select all applicable boxes

Yes	No	Saved costs
Yes	No	Improved time
Yes	No	Reduced risk
Yes	No	Improved quality
Yes	No	Adoption of mitigation action by implementer was good
Yes	No	Adoption of mitigation action by receiver was good
Yes	No	Skill level of users was sufficient
Yes	No	Skill level of receivers was sufficient
Yes	No	Contracts and general law approved the action

If other effects where present please elaborate on the blank space below

If you would like the publication to be sent to you electronically please ensure your email address is correct on the first page and tick this box.

☐

Sincere thanks for taking the time and effort to answer the questionnaire. Please be assured that the information will be treated as confidential and will be strictly used for academic purposes.

Kind regards

Jean-Jacques Kriel

jjk@sun.ac.za

Appendix D – Questionnaire Data

Time refers to the impact the area of concern has on project time. ***Cost*** refers to the impact the area of concern has on project cost. ***Quality*** refers to the impact the area of concern has on quality of project execution. ***Risk*** refers to the impact the area of concern has on increasing project risks.

1

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	10	8	10
Late in reviewing and approving design documents by consultant	10	10	8	10
Low productivity level of labourers	8	10	5	10
Ineffective planning and scheduling of project by contractor	10	10	7	10
Unqualified workforce	7	7	10	10
Delays in sub-contractors work	7	10	7	9
Inadequate experience of consultant	10	10	10	10
Equipment breakdowns	3	3	3	3
Accidents during construction	2	2	2	5

2

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	6	7	3	6
Late in reviewing and approving design documents by consultant	6	8	3	7
Low productivity level of labourers	7	8	5	3
Ineffective planning and scheduling of project by contractor	8	8	4	6
Unqualified workforce	8	8	6	7
Delays in sub-contractors work	7	4	4	6
Inadequate experience of consultant	7	7	3	7
Equipment breakdowns	7	6	4	7
Accidents during construction	6	5	4	6

3

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	8	8	5	6
Late in reviewing and approving design documents by consultant	8	8	5	8
Low productivity level of labourers	7	8	8	7
Ineffective planning and scheduling of project by contractor	8	8	6	7
Unqualified workforce	9	8	9	9
Delays in sub-contractors work	7	6	6	8
Inadequate experience of consultant	9	9	9	9
Equipment breakdowns	7	6	6	7
Accidents during construction	8	6	6	6

	Issue	Impact Area			
4		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	5
	Late in reviewing and approving design documents by consultant	10	10	5	5
	Low productivity level of labourers	8	8	7	7
	Ineffective planning and scheduling of project by contractor	9	9	7	10
	Unqualified workforce	5	7	8	8
	Delays in sub-contractors work	8	8	4	7
	Inadequate experience of consultant	10	10	6	10
	Equipment breakdowns	6	4	4	4
	Accidents during construction	8	8	2	8
5	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	6	9	9	8
	Late in reviewing and approving design documents by consultant	6	7	8	7
	Low productivity level of labourers	7	8	6	6
	Ineffective planning and scheduling of project by contractor	10	10	8	10
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	8	7	8	9
	Inadequate experience of consultant	9	9	9	9
	Equipment breakdowns	8	8	7	8
	Accidents during construction	8	8	7	8
6	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	5
	Late in reviewing and approving design documents by consultant	6	5	3	2
	Low productivity level of labourers	5	6	3	2
	Ineffective planning and scheduling of project by contractor	1	6	7	10
	Unqualified workforce	2	2	3	1
	Delays in sub-contractors work	7	8	6	6
	Inadequate experience of consultant	10	10	10	10
	Equipment breakdowns	2	6	3	8
	Accidents during construction	5	5	5	5

7

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	10	1	10
Late in reviewing and approving design documents by consultant	10	10	1	10
Low productivity level of labourers	10	10	10	10
Ineffective planning and scheduling of project by contractor	10	10	10	10
Unqualified workforce	10	10	10	10
Delays in sub-contractors work	10	10	8	10
Inadequate experience of consultant	10	10	5	10
Equipment breakdowns	10	10	1	10
Accidents during construction	10	10	1	10

8

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	10	10	10
Late in reviewing and approving design documents by consultant	10	10	10	10
Low productivity level of labourers	10	10	1	8
Ineffective planning and scheduling of project by contractor	10	10	10	10
Unqualified workforce	10	10	10	10
Delays in sub-contractors work	10	10	10	10
Inadequate experience of consultant	10	10	10	10
Equipment breakdowns	5	8	1	6
Accidents during construction	2	5	1	8

9

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	1	3	2	1
Late in reviewing and approving design documents by consultant	1	2	2	2
Low productivity level of labourers	8	10	10	10
Ineffective planning and scheduling of project by contractor	7	7	7	7
Unqualified workforce	7	7	8	8
Delays in sub-contractors work	6	6	7	8
Inadequate experience of consultant	1	1	1	1
Equipment breakdowns	6	9	9	9
Accidents during construction	8	8	8	10

10

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	10	2	0
Late in reviewing and approving design documents by consultant	10	10	2	4
Low productivity level of labourers	8	8	6	2
Ineffective planning and scheduling of project by contractor	10	10	6	6
Unqualified workforce	8	8	8	8
Delays in sub-contractors work	10	10	6	6
Inadequate experience of consultant	10	10	10	10
Equipment breakdowns	6	8	6	4
Accidents during construction	10	2	2	8

11

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	9	8	6	7
Late in reviewing and approving design documents by consultant	8	7	6	7
Low productivity level of labourers	7	8	6	6
Ineffective planning and scheduling of project by contractor	8	7	5	7
Unqualified workforce	8	7	8	6
Delays in sub-contractors work	8	6	7	6
Inadequate experience of consultant	9	8	7	7
Equipment breakdowns	6	7	5	6
Accidents during construction	8	8	6	6

12

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	8	6	7
Late in reviewing and approving design documents by consultant	10	8	6	6
Low productivity level of labourers	10	10	10	8
Ineffective planning and scheduling of project by contractor	10	10	8	10
Unqualified workforce	10	10	10	10
Delays in sub-contractors work	8	8	10	8
Inadequate experience of consultant	10	10	10	10
Equipment breakdowns	10	10	8	8
Accidents during construction	10	10	10	10

	Issue	Impact Area			
13		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	8	7	9
	Late in reviewing and approving design documents by consultant	7	5	5	6
	Low productivity level of labourers	5	5	6	4
	Ineffective planning and scheduling of project by contractor	8	8	8	8
	Unqualified workforce	8	9	7	6
	Delays in sub-contractors work	8	6	5	7
	Inadequate experience of consultant	7	5	3	8
	Equipment breakdowns	5	4	3	4
	Accidents during construction	3	2	2	5
14	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	9	9	6	8
	Late in reviewing and approving design documents by consultant	9	8	5	5
	Low productivity level of labourers	7	7	6	6
	Ineffective planning and scheduling of project by contractor	8	8	6	7
	Unqualified workforce	8	7	7	7
	Delays in sub-contractors work	5	5	6	5
	Inadequate experience of consultant	7	5	7	5
	Equipment breakdowns	4	4	3	4
	Accidents during construction	4	4	3	4
15	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	7	1	3
	Late in reviewing and approving design documents by consultant	7	8	1	5
	Low productivity level of labourers	7	8	5	8
	Ineffective planning and scheduling of project by contractor	10	10	5	10
	Unqualified workforce	8	8	10	10
	Delays in sub-contractors work	8	8	5	8
	Inadequate experience of consultant	6	7	5	7
	Equipment breakdowns	7	7	3	5
	Accidents during construction	7	7	3	8

16	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	6	10
	Late in reviewing and approving design documents by consultant	10	10	6	10
	Low productivity level of labourers	10	10	8	8
	Ineffective planning and scheduling of project by contractor	10	10	8	10
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	10	8	8	9
	Inadequate experience of consultant	9	9	6	10
	Equipment breakdowns	8	8	7	8
	Accidents during construction	10	8	5	6
17	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	8	8	8	8
	Late in reviewing and approving design documents by consultant	8	8	6	8
	Low productivity level of labourers	8	8	8	8
	Ineffective planning and scheduling of project by contractor	2	3	3	5
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	10	10	10	10
	Inadequate experience of consultant	10	10	10	10
	Equipment breakdowns	10	10	7	10
	Accidents during construction	10	10	10	10
18	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	1	10
	Late in reviewing and approving design documents by consultant	10	10	4	10
	Low productivity level of labourers	8	5	8	4
	Ineffective planning and scheduling of project by contractor	10	10	7	10
	Unqualified workforce	8	8	10	10
	Delays in sub-contractors work	8	2	3	8
	Inadequate experience of consultant	7	10	8	7
	Equipment breakdowns	8	8	8	9
	Accidents during construction	7	2	2	7

19

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	10	10	5	10
Late in reviewing and approving design documents by consultant	10	10	5	10
Low productivity level of labourers	7	7	2	3
Ineffective planning and scheduling of project by contractor	10	10	3	6
Unqualified workforce	9	8	8	5
Delays in sub-contractors work	8	6	2	5
Inadequate experience of consultant	10	5	1	5
Equipment breakdowns	7	8	6	4
Accidents during construction	6	6	2	3

20

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	7	10	7	5
Late in reviewing and approving design documents by consultant	10	5	8	7
Low productivity level of labourers	10	5	9	7
Ineffective planning and scheduling of project by contractor	10	8	7	5
Unqualified workforce	7	5	10	9
Delays in sub-contractors work	10	0	8	5
Inadequate experience of consultant	5	8	9	10
Equipment breakdowns	10	9	0	7
Accidents during construction	9	8	1	10

21

Issue	Impact Area			
	Time	Cost	Quality	Risk
Delay in approving major changes in the scope of work by consultant	5	5	5	5
Late in reviewing and approving design documents by consultant	5	6	3	3
Low productivity level of labourers	6	6	4	5
Ineffective planning and scheduling of project by contractor	2	1	0	2
Unqualified workforce	5	5	4	5
Delays in sub-contractors work	0	0	0	0
Inadequate experience of consultant	4	5	5	4
Equipment breakdowns	3	3	2	1
Accidents during construction	2	1	1	1

	Issue	Impact Area			
22		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	8	7	5	7
	Late in reviewing and approving design documents by consultant	8	7	5	7
	Low productivity level of labourers	8	8	7	7
	Ineffective planning and scheduling of project by contractor	9	9	8	8
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	10	10	5	9
	Inadequate experience of consultant	8	8	7	8
	Equipment breakdowns	10	10	5	7
	Accidents during construction	7	6	5	8
	Issue	Impact Area			
23		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	4	6	2	6
	Late in reviewing and approving design documents by consultant	5	6	1	7
	Low productivity level of labourers	5	6	2	6
	Ineffective planning and scheduling of project by contractor	3	6	1	7
	Unqualified workforce	4	7	2	6
	Delays in sub-contractors work	4	4	2	6
	Inadequate experience of consultant	6	6	3	7
	Equipment breakdowns	2	5	2	7
	Accidents during construction	1	3	1	6
	Issue	Impact Area			
24		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	10
	Late in reviewing and approving design documents by consultant	10	10	5	10
	Low productivity level of labourers	10	10	10	10
	Ineffective planning and scheduling of project by contractor	10	10	5	10
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	10	10	10	10
	Inadequate experience of consultant	10	10	5	10
	Equipment breakdowns	10	10	5	10
	Accidents during construction	10	10	5	10

	Issue	Impact Area			
25		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	8	7	6	8
	Late in reviewing and approving design documents by consultant	7	7	5	9
	Low productivity level of labourers	7	8	8	10
	Ineffective planning and scheduling of project by contractor	10	10	7	8
	Unqualified workforce	7	8	8	7
	Delays in sub-contractors work	8	6	8	7
	Inadequate experience of consultant	9	9	10	10
	Equipment breakdowns	7	7	6	7
	Accidents during construction	8	6	5	8
	Issue	Impact Area			
26		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	10
	Late in reviewing and approving design documents by consultant	10	10	5	10
	Low productivity level of labourers	8	8	8	8
	Ineffective planning and scheduling of project by contractor	5	6	6	8
	Unqualified workforce	5	8	8	8
	Delays in sub-contractors work	5	5	5	8
	Inadequate experience of consultant	10	10	10	10
	Equipment breakdowns	2	3	2	4
	Accidents during construction	2	2	2	8
	Issue	Impact Area			
27		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	7	7	7	7
	Late in reviewing and approving design documents by consultant	7	7	7	7
	Low productivity level of labourers	8	8	8	8
	Ineffective planning and scheduling of project by contractor	7	7	7	7
	Unqualified workforce	6	6	6	6
	Delays in sub-contractors work	5	5	5	5
	Inadequate experience of consultant	5	5	5	5
	Equipment breakdowns	2	2	2	2
	Accidents during construction	2	2	2	2

	Issue	Impact Area			
28		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	5	3	5	5
	Late in reviewing and approving design documents by consultant	5	5	5	5
	Low productivity level of labourers	7	7	7	7
	Ineffective planning and scheduling of project by contractor	5	5	5	5
	Unqualified workforce	5	5	5	5
	Delays in sub-contractors work	5	10	5	10
	Inadequate experience of consultant	5	5	5	5
	Equipment breakdowns	5	5	5	5
	Accidents during construction	5	5	5	5
29	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	10
	Late in reviewing and approving design documents by consultant	10	10	5	10
	Low productivity level of labourers	8	10	8	8
	Ineffective planning and scheduling of project by contractor	8	8	5	10
	Unqualified workforce	8	10	10	10
	Delays in sub-contractors work	10	10	5	10
	Inadequate experience of consultant	8	10	5	10
	Equipment breakdowns	8	8	5	8
	Accidents during construction	10	10	4	10
30	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	5	5
	Late in reviewing and approving design documents by consultant	8	8	5	5
	Low productivity level of labourers	8	8	8	8
	Ineffective planning and scheduling of project by contractor	7	8	8	8
	Unqualified workforce	8	8	8	8
	Delays in sub-contractors work	8	8	8	6
	Inadequate experience of consultant	7	8	8	7
	Equipment breakdowns	6	7	6	6
	Accidents during construction	10	10	6	9

31	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	8	8
	Late in reviewing and approving design documents by consultant	10	10	8	8
	Low productivity level of labourers	9	9	9	9
	Ineffective planning and scheduling of project by contractor	10	10	8	9
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	10	10	9	10
	Inadequate experience of consultant	10	10	10	10
	Equipment breakdowns	8	8	8	9
	Accidents during construction	10	10	10	10
32	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	5	6	3	3
	Late in reviewing and approving design documents by consultant	5	6	1	5
	Low productivity level of labourers	8	5	6	6
	Ineffective planning and scheduling of project by contractor	4	1	1	1
	Unqualified workforce	8	6	8	8
	Delays in sub-contractors work	6	6	6	6
	Inadequate experience of consultant	7	4	6	5
	Equipment breakdowns	2	2	2	2
	Accidents during construction	8	7	5	8
33	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	8	7	8
	Late in reviewing and approving design documents by consultant	9	8	8	8
	Low productivity level of labourers	10	10	8	9
	Ineffective planning and scheduling of project by contractor	10	10	9	9
	Unqualified workforce	8	7	7	7
	Delays in sub-contractors work	9	9	8	8
	Inadequate experience of consultant	8	8	6	6
	Equipment breakdowns	9	9	7	8
	Accidents during construction				

34	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	7	4	2
	Late in reviewing and approving design documents by consultant	10	8	4	3
	Low productivity level of labourers	7	7	5	7
	Ineffective planning and scheduling of project by contractor	8	8	5	8
	Unqualified workforce	6	7	8	6
	Delays in sub-contractors work	7	5	6	5
	Inadequate experience of consultant	5	6	5	4
	Equipment breakdowns	5	5	7	5
	Accidents during construction	2	1	1	3
35	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	10	1	10
	Late in reviewing and approving design documents by consultant	10	10	1	10
	Low productivity level of labourers	8	8	8	5
	Ineffective planning and scheduling of project by contractor	10	8	5	5
	Unqualified workforce	8	5	9	7
	Delays in sub-contractors work	8	7	3	9
	Inadequate experience of consultant	10	10	3	10
	Equipment breakdowns	5	5	3	5
	Accidents during construction	4	6	1	5
36	Issue	Impact Area			
		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	8	8	8
	Late in reviewing and approving design documents by consultant	10	8	6	7
	Low productivity level of labourers	10	8	5	8
	Ineffective planning and scheduling of project by contractor	10	10	10	10
	Unqualified workforce	7	7	10	8
	Delays in sub-contractors work	9	8	8	8
	Inadequate experience of consultant	9	9	9	10
	Equipment breakdowns	8	8	6	7
	Accidents during construction	8	8	5	7

	Issue	Impact Area			
37		Time	Cost	Quality	Risk
	Delay in approving major changes in the scope of work by consultant	10	8	6	7
	Late in reviewing and approving design documents by consultant	10	8	6	6
	Low productivity level of labourers	10	10	10	8
	Ineffective planning and scheduling of project by contractor	10	10	8	10
	Unqualified workforce	10	10	10	10
	Delays in sub-contractors work	8	8	10	8
	Inadequate experience of consultant	10	10	10	10
	Equipment breakdowns	10	10	8	8
	Accidents during construction	10	10	10	10
	Issue	Impact Area			
		Time	Cost	Quality	Risk
38	Delay in approving major changes in the scope of work by consultant	10	8	7	9
	Late in reviewing and approving design documents by consultant	7	5	5	6
	Low productivity level of labourers	5	5	6	4
	Ineffective planning and scheduling of project by contractor	8	8	8	8
	Unqualified workforce	8	9	7	6
	Delays in sub-contractors work	8	6	5	7
	Inadequate experience of consultant	7	5	3	8
	Equipment breakdowns	5	4	3	4
	Accidents during construction	3	2	2	5

Appendix E –Labour Productivity Measurement Techniques

E.1 Field rating

A field rating is a productivity measuring method which simply states the current ratio of workers "working" relative to the total amount of workers observed and is expressed as a percentage. The data is captured and logged whilst conducting the field rating on site (Dozzi & AbouRizk, 1993). The fact that foremen and supervisors generally do not perform physical tasks, and look as though they are not working, is accounted for by adding 10% to the ratio (Dozzi & AbouRizk, 1993). An example of how the calculation of a field study is done can be seen in Equation E.1.

According to Dozzi and AbouRizk (1993) a field rating of 60% or more should be achieved so that the productivity can be classified as satisfactory. The field study analyser should be aware that the observer could have a different interpretation of the word "working" and the correct interpretation should be clearly defined for specific activities.

$$Field\ rating = \frac{Total\ observations\ of\ labourers\ working}{Total\ number\ of\ observations\ made} \times \frac{100}{1} + 10\% \quad \text{..E.1}$$

E.2 Work Sampling

Work sampling is a relatively more sophisticated method of measuring productivity than that of a field rating. It involves statistical sampling where an operation is observed for a limited time period and a degree of productivity is deduced. This deduction is made by estimating the percentage of time a labourer is productive relative to the total time he or she is involved with the operation. The term 'productive' is used in a work sample and is a better describing word to use than 'working'. The worker's activity can be described by using various examples of activity classifications as seen in Table E.1 (Dozzi & AbouRizk, 1993).

Table E.1 - Labour activity classification examples for a work sample (Dozzi & AbouRizk, 1993).

Classification	Productive Direct work Working	Semi-Productive Indirect work Support Work	Non-Productive Delay Non-working
Description	Using trade tools	Supporting the main activity	Not contributing to the activity
Examples	Mason laying brick, Labourer mixing mortar Electrician pulling wire Welder welding pipe	Tradesman getting material Travelling to work location Taking instructions	Personal breaks Waiting for equipment Waiting for more instructions Late start Early departure

During a work sampling procedure there are a number of observations made at random times and an activity classification is chosen to describe the activity of the workforce. The amount of times a worker is classified within each activity classification is expressed relative to the total number of observations. This gives the analyst a breakdown of the percentage of time the operation was within a specific activity classification (Dozzi & AbouRizk, 1993). An example of an operation's breakdown of productivity can be seen in Table E.2.

Table E.2 shows that while doing observations of the brick laying activity, the workforce was productive 45% of the time. The workforce was semi-productive for 22% and non productive for 33% of the time. In order for the activity to be classified as acceptable, the activity classification should be productive for at least 30% of the time. This value varies and can range from 32%, as publicised by Civil Engineering magazine, and 46.7%, publicised by University of Texas (Dozzi & AbouRizk, 1993).

Table E.2 - Sampling of a brick laying operation (Dozzi & AbouRizk, 1993).

Operation: Brick Laying		Location: Main room A	
Observation No.	Productive	Semi-Productive	Non Productive
1	√		
2		√	
3	√		
4			√
5			√
6			√
7		√	
8	√		
9	√		
Total	4	2	3
Percentage	45%	22%	33%

Although a work study is more sophisticated, it only manages to measure productivity indirectly due to the fact that it measures if a worker is working or not and is unable to measure how effective the person is working. Work studies can therefore only measure if a carpenter is working or not, but not how many blows he takes to drive in a nail (Dozzi & AbouRizk, 1993).

E.3 Five minute rating

A five minute rating is another method used to determine the effectiveness of a crew of labourers. This method does not involve statistical sampling like the work sample method or the field rating method. Instead, it makes use of physical observations for a period of five minutes (Dozzi & AbouRizk, 1993). This method, therefore, gives the observer time to identify whether the observed crew members are active, for over half the observation time, or not. This method is similar to the work sampling method and also involves determining the percentage of workers active relative to the number of observations made (Dozzi & AbouRizk, 1993). If they are actively involved with the operation then a tick is made under their respective column at the time of observation. An example of such a five minute rating sheet can be seen in Table E.3 (Dozzi & AbouRizk, 1993).

All three of the mentioned methods already discussed can only identify how time is spent on an operation and not what causes the productivity to be lower. However, field surveys and questionnaires can be used to identify what the causes are of the delays or what the inefficiencies are in terms of productivity.

Table E.3 - Sample of a 5-minute-rating of a labour crew (Dozzi & AbouRizk, 1993).

Time	Spreader	Screeder	Grader	Bull Float
9h50	√	√	√	
9h55	√	√	√	
10h00				√
10h05	√	√	√	√
10h10	√		√	
10h15	√	√		√
10h20	√	√	√	√
10h25		√		√
Effective observations	6	6	5	5
Total observations	32	Effectiveness		22/32
Observed effective	22	5-minute rating		68%

Dozzi & AbouRizk (1993) stated that a foreman or a craftsman plays an integral part in identifying the causes of productivity inhibitors. They work close to the operation itself and are involved with the crew that are performing the tasks. A field study utilizes this knowledgeable resource and provides a structured way of involving the foreman or craftsman in the process of measuring and improving productivity. A field survey specifically made for foremen to identify sources of delay is called a foreman delay survey and an example can be seen in Table E.4 (Dozzi & AbouRizk, 1993).

Table E.4 - Foreman delay survey (Dozzi & AbouRizk, 1993).

Problem causing area	Person Hours lost			%
	No. of Hours Lost	No. of Workers	Total Person-Hours	
Redoing work (design error change)	15.25	8	122	2.3
Redoing work (prefabrication error)	6	4	24	0.5
Redoing work (field error/damage)	13	4	52	1.0
Waiting for materials (warehouse)	5.5	6	33	0.6
Waiting for materials (vendor furnished)	5.5	4	22	0.4
Waiting for tools	6	2	12	0.2
Waiting for construction equipment	8	7	56	1.1
Construction equipment breakdown	5	3	15	0.3
Waiting for information	3	4	12	0.2
Waiting for other crews	3.5	4	14	0.3
Waiting for fellow crew members	2.5	4	10	0.2
Unexplained or unnecessary move	4	5	20	0.4
Other:	10	7	70	1.3
Total:			462	8.9
Total work in person-hours			5210	
Comments:				
Made by:				
Date:				

A typical foreman delay survey can be seen in Table E.4 and shows that design errors create the most rework and influences the productivity of the labourers in the crew the most (Dozzi & AbouRizk, 1993). Waiting for construction equipment also seems to have a great impact on the time labourers lose on site (Dozzi & AbouRizk, 1993).

A field survey conducted by the foreman or craftsman is thus an accurate way of determining the sources where the productivity of the crew is inhibited. Table E.4 is populated by areas of concern that may seem typical to any construction site but these are not a generic set of problem areas. A craftsman questionnaire is a good way of identifying these areas of concern. The questionnaire asks questions to the craftsman to identify what areas inhibit his/her productivity and motivation. This is done by determining how many person hours are lost due to specific factors during construction. An example of such a craftsman questionnaire can be seen in Table E.5

Table E.5 - Example of a craftsman questionnaire (Dozzi & AbouRizk, 1993).

Craftsman Questionnaire	Craft:	
Type of work:	Location:	
Tick√ the appropriate box to indicate YES or NO or fill the box with the required information		
	YES	NO
MATERIAL		
Is material always available when you need it?		
How many hours do you estimate are lost per week due to material not being available?	________________hours	
TOOLS		
Are tools always available when you need them?		
Are tools in acceptable state?		
Are tools supplied always the right ones for the job?		
Are there any tools in short supply (please name)		
How many hours do you estimate are lost per week due to tools not being available or acceptable for the job?	________________hours	
EQUIPMENT		
Question 1(Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to equipment not being available or acceptable for the job?	________________hours	
REWORK		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to rework?	________________hours	
SAFETY CONCERNS		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to safety concerns?	________________hours	
OTHERS		
Question 1 (Add more questions as under material and tools)		
Question 2 (Add more questions as under material and tools)		
How many hours do you estimate are lost per week due to other inhibitors?	________________hours	

E.4 Method productivity delay model

The Method Productivity Delay Model (MPDM) makes use of an observer who records data on a specific form. The data collected is focused on the resources doing specific operations and the times involved doing the tasks within the operation. This is thus a more detailed way of measuring productivity and makes use of some of the work study principles explained earlier in section E.1.

Productivity improvements can follow from the use of this method because the MPDM focuses on the identification of delays and time losses during cycle times (Dozzi & AbouRizk, 1993). The identified delays are put into perspective by computing the contribution of each source of delay to the loss in productivity. Once data capturing is complete, calculations are done to express the data and statistics of specific performance factors. Experience with the use of the MPDM has shown that a software package should be used to simplify the calculations and to get results faster (Dozzi & AbouRizk, 1993).

MPDM works in five phases which start with the identification of the production unit and the production cycle (Dozzi & AbouRizk, 1993). The production unit is the main resource involved with the operation that can be easily identified. In building a wall the production unit would be a brick or even a row of bricks, depending on the level of the investigation. In casting a floor a bucket of concrete would represent the production unit. The production cycle on the other hand refers to the time used to produce one production unit (Dozzi & AbouRizk, 1993). This could be the time used to lay one brick or one row of bricks. In casting a floor this would be the time taken to place one bucket of concrete.

The second phase of the MPDM is to identify the leading resource. This is regarded as the main resource that has the biggest influence on the productivity of the production cycle. Without the leading resource the operation will come to a standstill. Examples include the mason in brick laying or the crane in concrete placing using a bucket.

The third phase is the identification of the types of delay that can be encountered in the process. Dozzi & AbouRizk (1993) state that each user should identify their own sources of delays but use the sources such as environment, equipment, labour, material and management.

The fourth phase of the MPDM is the data collection which involves timing of the operation cycle as well as delays encountered within the cycles of the operation. Table E.6 shows an example of a data collection sheet on which data of the MPDM was taken down for the installation of roof trusses. The delays that were identified were classified in terms of the categories chosen in phase three of the MPDM.

The final stage of using the MPDM is to analyse the data that was collected (Dozzi & AbouRizk, 1993). This involves doing calculations as seen in Table E.7 and Table E.8. Column (7) of Table E.6 is calculated by taking the specific cycle time (column 1 of Table E.6) and subtracting the average cycle time of the cycles with no delays. The value in column 7 of table E.6 should be converted to a positive value for calculation purposes.

Table E.6 - MPDM data collection sheet of the installation of roof trusses (Dozzi & AbouRizk, 1993).

MPDM Data Collection Sheet							
				DATE: June 6, 1992			
OPERATION: Roof truss installation				OBSERVER: SAM			
PRODUCTION UNIT: One truss				UNIT OF TIME: Second			
Production Cycle	**Cycle time**	**Environ. Delay**	**Equip. Delay**	**Labour Delay**	**Material Delay**	**Management Delay**	**Processing column**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	354						12.83
2	465		X				98.17
3	343						23.83
4	445	X					76.17
5	504				X		137.17
6	470		X				103.17
7	395						28.17
8	345						21.83
9	360						6.83
10	353						33.17
11	460		X				93.17
12	385						18.17
13	360						6.83
14	353						13.83
15	372						5.17
16	505			X50%		X50%	138.17
17	465					X	98.17
18	440					X	73.17
19	430	X					63.17
20	360						6.83
21	375						8.17
22	405		X				38.17
23	475		X				108.17

Table E.7 - Processing of MPDM sample data (Dozzi & AbouRizk, 1993).

	Production Total Time	Number of cycles	Mean Cycle time	∑[Cycle time – Average Non delay cycle time]/n
	(1)	(2)	(3)	(4)
Non-delayed production cycles	4 402	12	366.83	15.47
Overall production cycles	9 466	23	411.57	52.81

The production total time of the non-delayed production cycles (column 1, row 1 of Table E.7) is calculated by adding the cycle times (column 1 of Table E.6) where no delays were observed. The overall production cycle times (column 1, row 2 of Table E.7) are calculated by adding all the cycle times in column 1 of Table E.6. The number of cycles of the non-delayed production cycles (column2, row1 Table E.7) is calculated by counting the number of cycles in Table E.6 that had no delays. Column 2, row 2 of Table E.7 is calculated by counting all the cycles in Table E.6. The mean cycle time (column 3 in Table E.7) is calculated by taking column 1 of Table E.7 and dividing it by column 2 of Table E.7. The value in column 4, row 1 of Table E.7 is the average of the values of the cycles in column 7 of Table E.6 that had no delays. The value in column 4, row 2 of Table E.7 is the average of all the values of the cycles in column 7 of Table E.6.

Table E.8 - Delay information for sample MPDM (Dozzi & AbouRizk, 1993).

Time variance	Environment	Equipment	Labour	Material	Management
	(1)	(2)	(3)	(4)	(5)
No of occurrences	2	5	1	1	3
Total added time	141.3	440.8	69.1	137.2	240.4
Probability of occurrence	0.09	0.22	0.04	0.04	0.13
Relative severity	0.17	0.21	0.17	0.33	0.19
Expected percentage of delay	0.01	0.05	0.01	0.01	0.03

The number of occurrences (row 1 in Table E.8) is calculated by counting the number of times a specific source of delay was identified in Table E.6. The total added time (row 2 of Table E.8) for a respective source of delay is calculated by adding the times in column 7 of Table E.6 when that specific source was identified as a delay in that cycle. The probability of occurrence (row 3 in Table E.8) is determined by dividing the number of occurrences of the delay (row 1 in Table E.8) with the total number of cycles (first column in Table E.6) The relative severity is calculated by taking the total added time (row 2 of Table E.8) divided by the number of occurrences (row 1 of Table E.8) divided by the mean cycle time (column 3 in Table E.7) of all the cycles (Dozzi & AbouRizk, 1993).

After these tables are populated the Overall Method Productivity (OMP) can be calculated with equation E.2 (Dozzi & AbouRizk, 1993). Equation E.3 and E.4 are the next steps towards calculating the OMP and the answer can be seen to be 0.002426 trusses per second or 8.73 trusses per hour (Dozzi & AbouRizk, 1993).

$$OMP = (Ideal\ Productivity)(1 - \sum expected\%\ of\ delay\ time) \quad \text{E.2}$$

$$OMP = \left(\frac{1}{mean\ cycle\ time\ of\ non\ delay\ cycles}\right)(1 - \sum expected\%\ of\ delay\ time) \text{.........................} E.3$$

$$OMP = \left(\frac{1}{366.83}\right)(1 - 0.11) \text{.........................} E.4$$

$$= 0.002426\ trusses/second$$

$$= 8.73\ trusses/hour$$

The final step of the MPDM is to calculate the Ideal Cycle Variability (ICV) and Overall Cycle Variability (OCV) of the operation productivity (Dozzi & AbouRizk, 1993). The ideal productivity is calculated with Equation E.5 and expanded in Equation E.6 (Dozzi & AbouRizk, 1993). The overall productivity is calculated with Equation E.7 and expanded in Equation E.8 (Dozzi & AbouRizk, 1993).

$$ICV = \frac{\left(\frac{\sum[(\text{Cycle time of non delay cycles}) - (\text{Average Non delay cycle time})]}{\text{Number of cycles}}\right)}{(\text{Mean Cycle time for non delay cycles})} \text{.........................} E.5$$

$$ICV = (\text{Row 1, Col. 4, Table E. 7}) / (\text{Row 1, Col. 3, Table E. 7}) \text{.........................} E.6$$

$$= 15.47/366.83$$

$$= 4\%$$

$$OCV = \frac{\left(\frac{\sum[(\text{Cycle time of delayed cycles}) - (\text{Average Non delay cycle time})]}{\text{Number of cycles}}\right)}{(\text{Mean Cycle time for all cycles})} \text{.........................} E.7$$

$$OCV = (\text{Row 2, Col. 4, Table E. 7})/(\text{Row 2, Col. 3, Table E. 7}) \text{.........................} E.8$$

$$= 52.81/411.57$$

$$= 12.8\%$$

The variation between ICV and OCV is considered minor and the productivity information derived can be taken as sound and reliable.

E.5 Charting techniques

Charting techniques is another productivity measuring method that will be discussed and is used to compare the interrelationships of the workers and the equipment required to complete a task. The operation is monitored by an individual or with the use of time lapse film (Dozzi & AbouRizk, 1993). If an individual is used to monitor the operation, many cycles must be monitored in order to get the time breakdown of each worker in a cycle. If time-lapse photography is used, one cycle can be analysed and all the workers and equipment can be timed within one cycle (Dozzi & AbouRizk, 1993).

A crew balance chart is constructed by drawing vertical bars, each representing a resource which could be a worker or a piece of equipment used during a work cycle (Dozzi & AbouRizk, 1993). The vertical bars are drawn using the scale of the cycle time and therefore, because all the resources are present in the cycle, all the bars have the same length (Dozzi & AbouRizk, 1993). The different states in which the resources are during the cycle can be seen in Figure E.1.

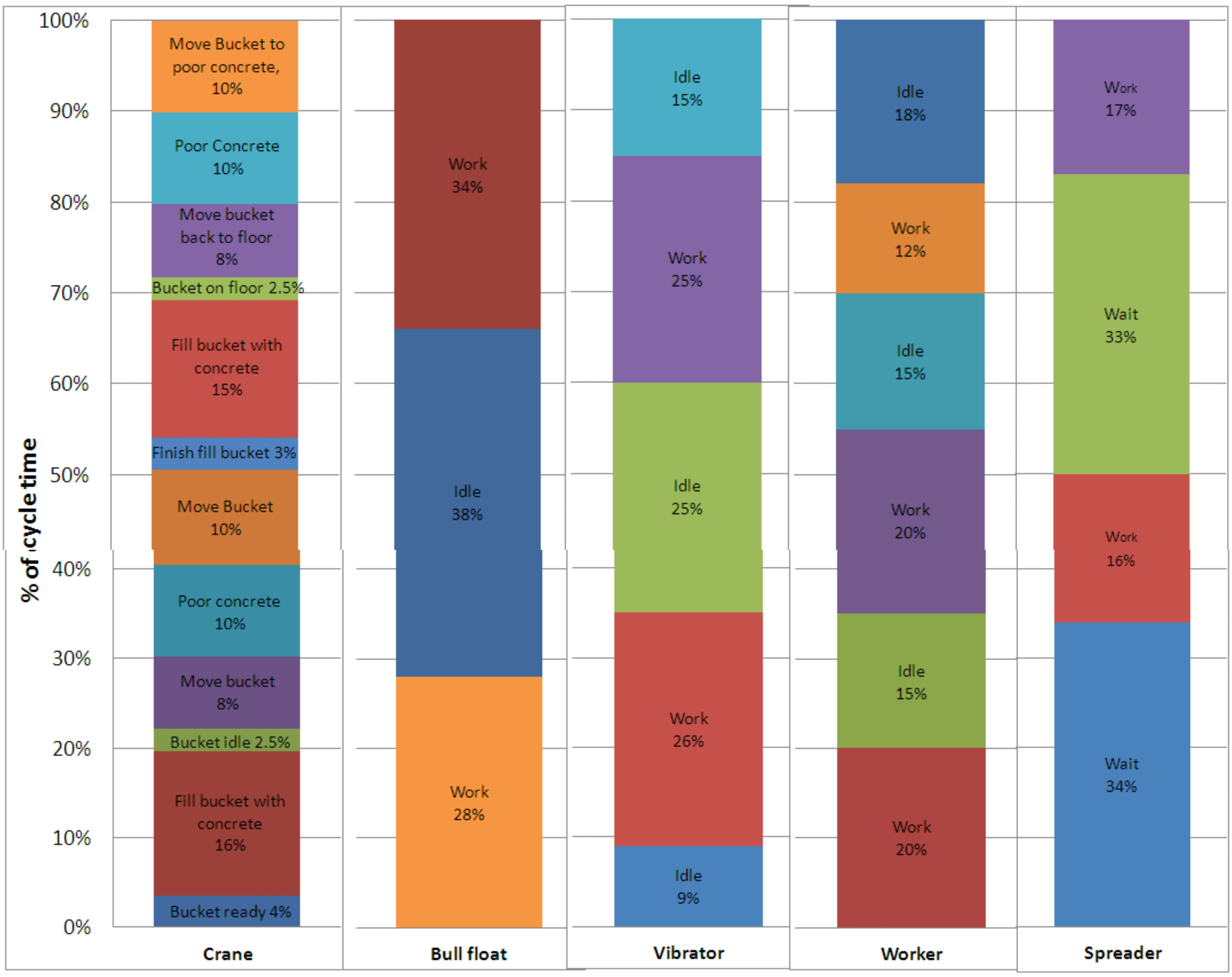


Figure E.1 - Crew balance chart for a concrete floor operation cycle (Dozzi & AbouRizk, 1993).

The different states in which a resource can be in include working, waiting, idle, or other defined actions aimed at the operation. Figure E.1 shows the operation of concrete placement with resources including a crane, bull float, vibrator, worker and a spreader. A horizontal line can be drawn to symbolise a given time in the cycle. The state of the different resources at that given time can be read off the bars at the point of intersection of the specific vertical bar and the line.

The user of the crew balance chart can take remedial action regarding low productivity by identifying the ideal crew size that an operation should have. The user is also stimulated to think of more efficient ways to perform the operation and how to fully utilize the workers in an alternative method.

E.6 Simulation modelling

Simulation modelling is the most technologically advanced method of all the methods mentioned in this section. The CYCLONE is one simulation modelling method that can be used to do an activity simulation. Although various other methods exist, the CYCLONE method has shown the most promise in construction modelling. Simulating with the CYCLONE methodology aims at building a mathematical- or logical model of a work system and experimenting with alternative methods and resource arrangements on a computer.

The CYCLONE methodology simulation consists of two main phases. The first phase is the modelling of the simulation and the second phase is to experiment with the model. The first phase of modelling is very similar to creating a critical path on a project scheduling software package. In both the Critical Path Method (CPM) and the CYCLONE method there are tasks, resources and specific orders of tasks and built in relationships and constraints. A CPM is, however, different from the CYCLONE method because the CYCLONE method focuses on the dynamic movement of resources whereas the CPM is regarded as static (Dozzi & AbouRizk, 1993).

CYCLONE modelling requires the user to model with given CYCLONE elements that represent different actions and resources. These can be seen in Figure E.3 with a description of what each element means and how it can be used in the simulation structure (Dozzi & AbouRizk, 1993). The identification of the resources in the operation should be done at the start of the modelling procedure and followed by defining the tasks that need to be performed during the operation. Following the task identification, a list of restraints and rules should be made to understand which tasks can be performed under which conditions. An example of a task restraint is when a task requires the simultaneous presence of two specific resources. If one resource is not available, the task cannot begin and the resource that is present needs to go into a state of waiting as opposed to a working state.

A sample of a CYCLONE model for an earth moving operation can be seen in Figure E.4. This figure shows that different elements are linked in specific ways to create a specific effect. The resources that are dependent on other requirements are marked differently and tasks that require more than one resource are also easily distinguished.

The results of a simulation can be seen in Figure E.5 and Figure E.6. Figure E.5 shows how the productivity can be calculated and expressed on a graph for analysis. Figure E.6 will be beneficial to the quantity surveyors as it shows unit costs and production given a specific amount of trucks in use. Figure E.6 shows the unit cost and production of trucks during an earthwork CYCLONE simulation.

CYCLONE Element	Description and rules for Model Building
NORMAL	The NORMAL is not a restrained task. Any resource that arrives at a NORMAL is given access and is immediately processed. It is similar to a serving station with an infinite number of servers. NORMAL can be preceded by all other CYCLONE elements except for a QUEue node. Can be followed by all other elements except for a COMBI.
COMBI	A task that is restrained by the availability of more than one type of resource. A resource arriving at a COMBI will have to wait until all other required resources are available before it is given access to the task. Can be preceded by QUEue nodes only. Can be followed by all other elements except COMBIs.
QUEue	A QUEue node is a waiting area for a resource. Therefore it is used only when a task is restrained. A resource arriving at a QUEue node will stay in the node until a COMBI is ready to process it. A QUEue has one other function when used in the MicroCYCLONE implementation, namely to multiply resources when specified. In other words, a modeler can specify that once a resource enters a specified QUEue mode, it will multiply into a finite number of duplicate resources. A QUEue can be preceded by any element except a QUEue node. Can be followed by COMBIs only.
FUNCTION	The FUNCTION element was devised to provide some flexibility. Different computer implementations of CYCLONE have somewhat different functions. In MicroCYCLONE, one type of function is allowed, namely the consolidate function. Its job is to take units and consolidate them into a specified number. Any unit arriving at this function will accumulate until a threshold value is reached, at which point only one unit is released from the function (all others are destroyed). Can be preceded by all elements except QUEue nodes. Can be followed by all elements except COMBIs.
COUNTER	The COUNTER keeps track of the number of times units pass. It does not alter any of the resources or their properties. It just adds increments and keeps track of cycles and a few other statistics. Can be preceded by all elements except QUEue nodes. Can be followed by all elements except COMBIs.

Figure E.2 - CYCLONE method modelling elements and description (Dozzi & AbouRizk, 1993).

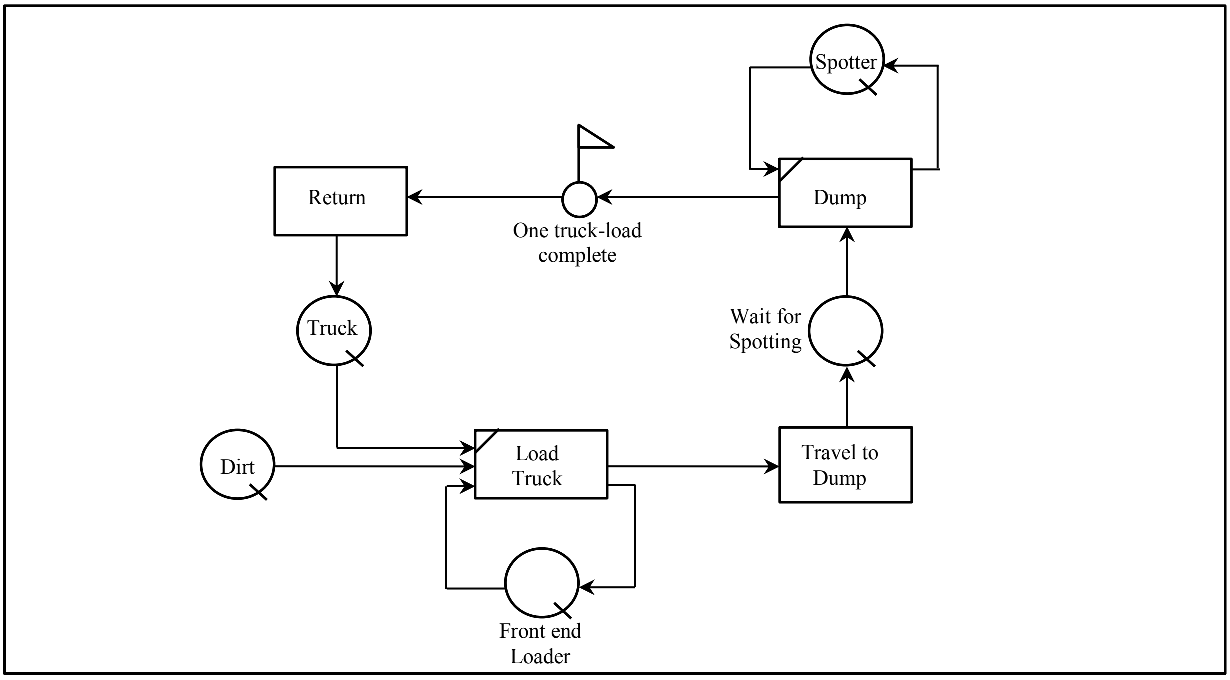


Figure E.3 - CYCLONE simulation model for an earth moving operation (Dozzi & AbouRizk, 1993).

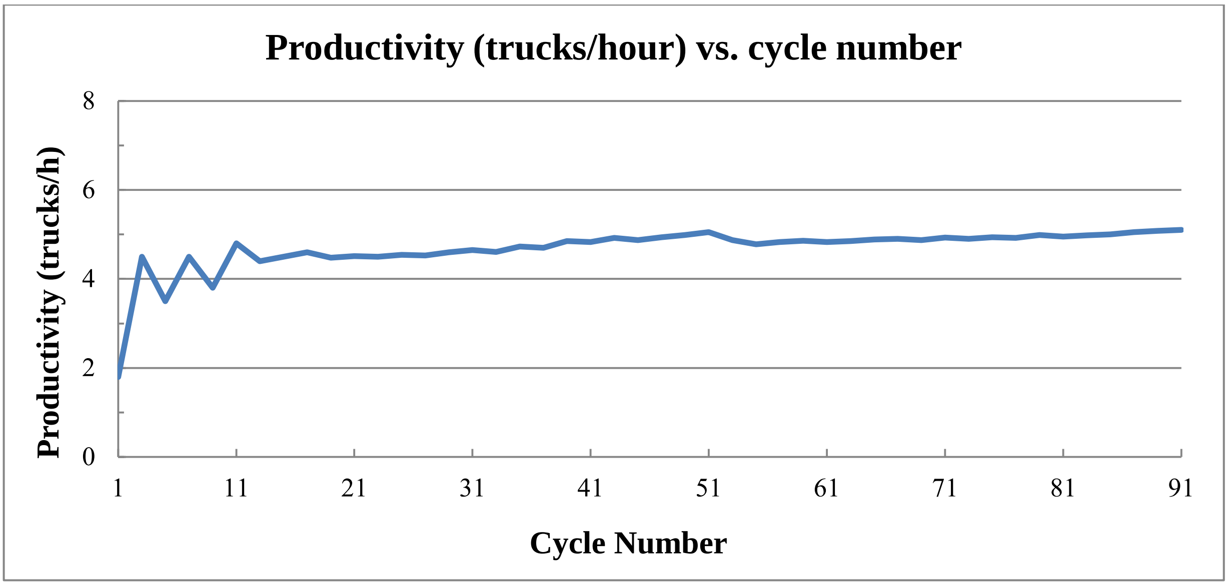


Figure E.4 - Productivity during a CYCLONE simulation of an earth moving operation (Dozzi & AbouRizk, 1993).

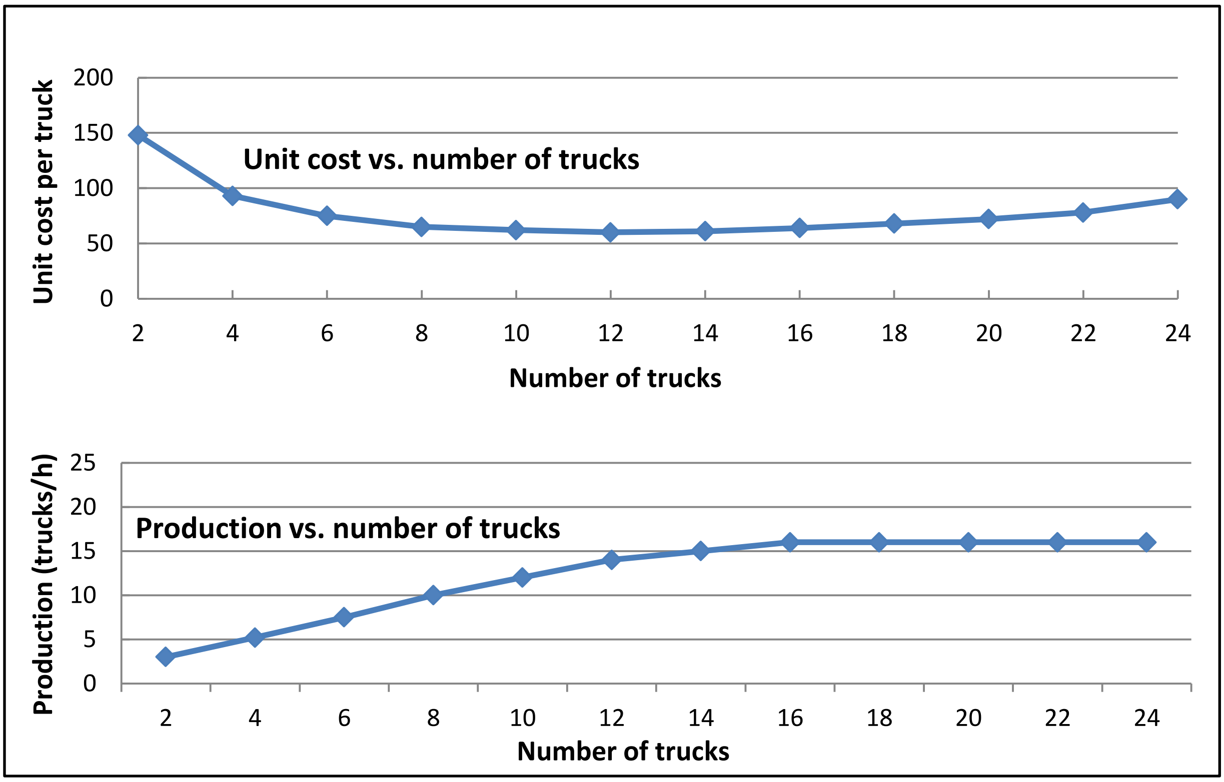


Figure E.5 - Unit cost and production of trucks during an earthwork CYCLONE simulation (Dozzi & AbouRizk, 1993).

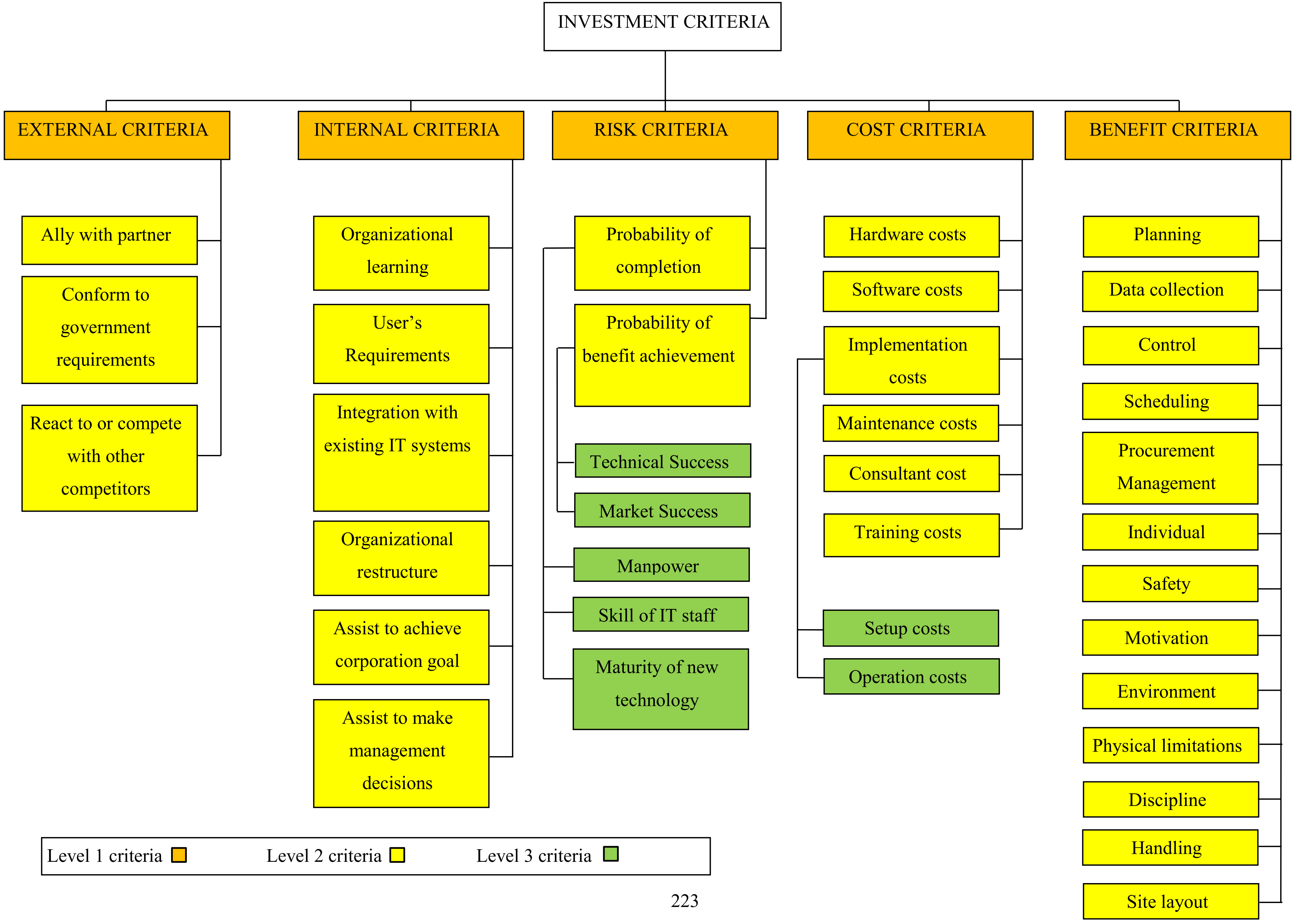
Simulation can be very useful in planning productive operations and understanding what factors influence productivity. Simulation has even been used to quantify the effect of a delay caused by a change in the operation cycle of construction. These quantified effects, along with the model, were used for claims regarding loss of productivity (Dozzi & AbouRizk, 1993). Similar studies can be conducted with simulation to analyse the effect of human factors on productivity (Dozzi & AbouRizk, 1993).

These different models of measuring productivity described in sections E.1 to E.6 had positive effects and negative effects with regard to the use and implementation of the models. According to Dozzi & AbouRizk (1993) these methods are tried and tested methods. However, the construction industry is regarded as a craft orientated industry and has not taken the necessary action to utilize advanced tools to improve productivity (Dozzi & AbouRizk, 1993). The reason could be because of the effort or difficulty of implementing these models. In Chapter 5 these models of productivity were further investigated to identify downfalls of each of the measuring methods.

Appendix F – Criteria used in IT/IS decision making

Criteria	Source
Ally with partner (Improve partner relations)	(Bacon, 1992) (Jones & Beatty, 1998) (Irani, 2002) (Mirani & Lederer, 1998) (Iacovou, et al., 1995)
Government requirement	(Escobar-Perez, 1998) (Bacon, 1992)
React to competition	(Mirani & Lederer, 1998) (Bacon, 1992) (Escobar-Perez, 1998)
Organizational learning	(Ryan & Harrison, 2000) (Escobar-Perez, 1998) (Bacon, 1992)
Technical/system requirements (User's requirement)	(Escobar-Perez, 1998) (Bacon, 1992)
Compatibility with existing IT/IS portfolio	(Jones & Beatty, 1998)
Probability of completion	(Escobar-Perez, 1998) (Bacon, 1992)
Manpower (staff resource)	(Ryan & Harrison, 2000) (Irani, 2002) (Mirani & Lederer, 1998)
Competence of project leader	(Irani, 2002) (Iacovou, et al., 1995)
Maturity of IT	(Chou, et al., 2006)
Probability of benefit achievement	(Escobar-Perez, 1998) (Bacon, 1992)
Hardware cost	(Jones & Beatty, 1998) (Iacovou, et al., 1995) (O'Callaghan, et al., 1992)
Software cost	(Jones & Beatty, 1998) (Mirani & Lederer, 1998) (O'Callaghan, et al., 1992)
Implementation costs	(Jones & Beatty, 1998) (Ryan & Harrison, 2000) (Iacovou, et al., 1995) (O'Callaghan, et al., 1992)
Maintenance cost	(Ryan & Harrison, 2000) (Irani, 2002) (Mirani & Lederer, 1998) (Iacovou, et al., 1995)
Consultant cost	(Irani, 2002) (Jones & Beatty, 1998) (Iacovou, et al., 1995)
Assist to achieve corporation goal	(Escobar-Perez, 1998) (Bacon, 1992) (Mirani & Lederer, 1998)
Assist planning and control	(Escobar-Perez, 1998) (Bacon, 1992) (Mirani & Lederer, 1998) (Irani, 2002)
Assist to make management decisions	(Escobar-Perez, 1998) (Bacon, 1992) (Mirani & Lederer, 1998) (Irani, 2002) (Ryan & Harrison, 2000)
Improve competitive advantage	(Mirani & Lederer, 1998) (Iacovou, et al., 1995) (Banerjee & Golhar, 1994)
Improve company image	(Banerjee & Golhar, 1994) (Irani, 2002)
Reduce operation cost	(Jones & Beatty, 1998) (Mirani & Lederer, 1998) (O'Callaghan, et al., 1992) (Irani, 2002) (Banerjee & Golhar, 1994) (Iacovou, et al., 1995)
Improve information quality	(Jones & Beatty, 1998) (Iacovou, et al., 1995)
Improve user satisfaction	(Jones & Beatty, 1998)
System flexibility	(Irani, 2002) (Mirani & Lederer, 1998)
Improve utilisation of equipment	(Ryan & Harrison, 2000) (Irani, 2002)
Improved cash flow	(Jones & Beatty, 1998) (Iacovou, et al., 1995)
Organisational restructure	(Jones & Beatty, 1998) (Irani, 2002) (O'Callaghan, et al., 1992)
Improved organisational teamwork/communication	(Ryan & Harrison, 2000) (Irani, 2002) (Mirani & Lederer, 1998) (Banerjee & Golhar, 1994)
Promotes concept of open culture	(Irani, 2002)
Formalize procedures with accountability and responsibility	(Irani, 2002)
Security or protection	(Irani, 2002)

Appendix G – Criteria structure for investment decisions regarding labour productivity improvement technology

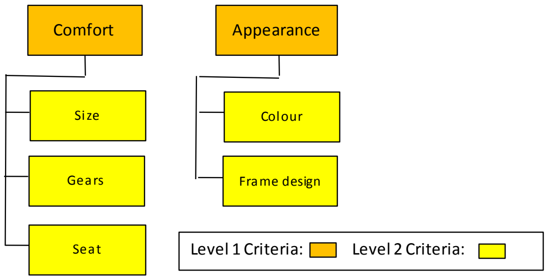

INVESTMENT CRITERIA
EXTERNAL CRITERIA
INTERNAL CRITERIA
RISK CRITERIA
COST CRITERIA
BENEFIT CRITERIA
Ally with partner
Conform to government requirements
React to or compete with other competitors
Organizational learning
User's Requirements
Integration with existing IT systems
Organizational restructure
Assist to achieve corporation goal
Assist to make management decisions
Probability of completion
Probability of benefit achievement
Technical Success
Market Success
Manpower
Skill of IT staff
Maturity of new technology
Hardware costs
Software costs
Implementation costs
Maintenance costs
Consultant cost
Training costs
Setup costs
Operation costs
Planning
Data collection
Control
Scheduling
Procurement Management
Individual
Safety
Motivation
Environment
Physical limitations
Discipline
Handling
Site layout
Level 1 criteria
Level 2 criteria
Level 3 criteria

Appendix H – Example of the implementation of the fuzzy-AHP MCDM

Multi criteria decision on bicycle

Step 1, Step 2 and Step 3:

Andrew, Sipho and John are three stakeholders of a company called Champion Courier and they need to make a decision between two types of bicycles. They want to use one of these types of bicycles to increase productivity in their mail delivery business. Champion Courier is subcontracted to deliver drawings and important documents by hand between the sites of two large construction projects. Andrew, Sipho and John will be used as the members of both the weighting and scoring team for this decision. They will receive one type of bicycle for free from the sponsoring construction company and they have to make a decision on which type of bicycle they want to use. They consider the **comfort** and **appearance** of the bicycle as important aspects to incorporate in the decision. This is done because the employees, doing the deliveries, ride for long hours during the day and because the Champion Courier is a new company and the appearance of the bicycle is important for the marketing strategy. Within the first level criteria there are sub-criteria which are on the second level. These second level criteria include the **size** of the bike, whether the bike has **gears,** the comfort of the **seat,** the **colour** of the bike and the **frame design** of the bike. The criteria structure can be seen below:



Matrix Number	Level of criteria	Criteria description	Level of parent	Parent
1	1	Comfort	NA	NA
		Appearance	NA	NA
2	2	Size	1	Comfort
		Gears		
		Seat		
3	2	Colour	1	Appearance
		Frame design		

Bicycle type 1: Silverback

Includes: 7 gears, comfortable seat, large frame and wheel trimmings

Bicycle type 2: Pelikaan

Includes: 1 gear, small seat and small folding frame which is very trendy.

As described in section 7.4.5 of this thesis document the criteria structure of the decision dictates the amount of fuzzy reciprocal matrices (FRM) that each decision maker has to construct. The structure of this example requires each member of the weighting team to construct 3 different FRMs. The table used in this example shows the different matrices and what criteria are compared in each FRM.

Step 4 and Step 5:

There are 3 FRM that each member of the weighting team needs to construct.
The 1st FRM is where the level 1 criteria are put through a pairwise comparison. The criteria are as follows: 1)Comfort 2)Appearance.
The 2nd FRM is where the level 2 criteria of Comfort are put through a pairwise comparison. The criteria are as follows: 1)Size 2)Gears 3)Seat.
The 3rd FRM is where the level 2 criteria of Appearance are put through a pairwise comparison. The criteria are as follows: 1)Colour 2)Frame design.

Below are the 3 FRMs constructed by each stakeholder using equation 7.3.

[FRM]

Linguistic terms from Table 7.2 / Linguistic terms transformed into TFN using Table 7.2

Andrew 1

1.0	VSMI	1 1 1	2 2 1/2 3
1/VSMI	1.0	1/3 2/5 1/2	1 1 1

Andrew 2

1.0	1/MMI	1/SMI	1 1 1	1/2 2/3 1	2/5 1/2 2/3
MMI	1.0	1/WMI	1 1 1/2 2	1 1 1	2/3 1 2
SMI	WMI	1.0	1 1/2 2 2 1/2	1/2 1 1 1/2	1 1 1

Andrew 3

1.0	EI	1 1 1	1 1 1
EI	1.0	1 1 1	1 1 1

Linguistic terms from Table 7.2 | Linguistic terms transformed into TFN using Table 7.2

[FRM]

Sipho 1

1.0	1/MMI	1	1	1	1/2	2/3	1
MMI	1.0	1	1 1/2	2	1	1	1

Sipho 2

1.0	1/SMI	EI	1	1	1	2/5	1/2	2/3	1	1	1
SMI	1.0	SMI	1 1/2	2	2 1/2	1	1	1	1 1/2	2	2 1/2
1/EI	1/SMI	1.0	1	1	1	2/5	1/2	2/3	1	1	1

Sipho 3

1.0	1/AMI	1	1	1	2/7	1/3	2/5
AMI	1.0	2 1/2	3	3 1/2	1	1	1

[FRM]

John 1

1.0	1/(AMI)	1	1	1	2/7	1/3	2/5
(AMI)	1.0	2 1/2	3	3 1/2	1	1	1

John 2

1.0	VSMI	EI	1	1	1	2	2 1/2	3	1	1	1
1/VSMI	1.0	1/SMI	1/3	2/5	1/2	1	1	1	2/5	1/2	2/3
1/EI	SMI	1.0	1	1	1	1 1/2	2	2 1/2	1	1	1

John 3

1.0	1/MMI	1	1	1	1/2	2/3	1
MMI	1.0	1	1 1/2	2	1	1	1

Step 6: Aggregated Fuzzy Reciprocal matrices in TFN format using Equation 7.4 and taking K=3

[FR̃M]

Aggr. 1

1.000	1.000	1.000	0.659	0.822	1.063
0.941	1.216	1.518	1.000	1.000	1.000

= (⅔ x 1 x 1)^(⅓)

Aggr. 2

1.000	1.000	1.000	0.737	0.941	1.260	0.737	0.794	0.874
0.794	1.063	1.357	1.000	1.000	1.000	0.737	1.000	1.494
1.145	1.260	1.357	0.669	1.000	1.357	1.000	1.000	1.000

Aggr. 3

1.000	1.000	1.000	0.523	0.606	0.737
1.357	1.651	1.913	1.000	1.000	1.000

Step 7: Geometric row means using equation 7.8

ri

0.812	0.907	1.031
0.970	1.103	1.232

= [(1.518) x (1.00)]^(½)

0.816	0.907	1.032
0.836	1.020	1.266
0.915	1.080	1.226

= [(1.357) x (1.357) x(1.00)]^(⅓)

0.723	0.778	0.858
1.165	1.285	1.383

= [(1.651) x (1.00)]^(½)

w i Normalised row means using equation 7.9

Comfort	0.456	0.451	0.456
Appearance	0.544	0.549	0.544

Size	0.318	0.302	0.293
Gears	0.326	0.339	0.359
Seat	0.356	0.359	0.348

= (0.836) x (0.816 + 0.836 + 0.915)^(-1)

Colour	0.383	0.377	0.383
Frame	0.617	0.623	0.617

Global weights of the criteria using equation 7.10

Comfort	0.456	0.451	0.456
Appearance	0.544	0.549	0.544
Size	0.145	0.136	0.133
Gears	0.148	0.153	0.164
Seat	0.174	0.170	0.174
Colour	0.209	0.207	0.209
Frame	0.336	0.342	0.336

= (0.451) 1st level criteria local=global weight

= (0.549) x (0.377)

Step 8:

Scoring of alternatives using Linguistic terms from Table 7.4

		Comfort	Appearance	Size	Gears	Seat	Colour	Frame
Andrew [X]	Silverback	VH.	H	H	H	H	M	H
	Pelikaan	M	H	M	VL	L	M	H

		Comfort	Appearance	Size	Gears	Seat	Colour	Frame
Sipho [X]	Silverback	VH.	VH.	H	VH.	M	H	H
	Pelikaan	H	H	M	L	L	H	VH.

		Comfort	Appearance	Size	Gears	Seat	Colour	Frame
John [x]	Silverback	H	H	H	H	M	H	H
	Pelikaan	H	VH.	VH.	M	H	H	VH.

Andrew's scoring of alternatives (TFN) from Table 7.4

Comfort			Appearance			Size			Gears			Seat			Colour			Frame		
0.7	0.9	1.0	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.5	0.7	0.9
0.3	0.5	0.7	0.5	0.7	0.9	0.3	0.5	0.7	0.0	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.7	0.5	0.7	0.9

Sipho's scoring of alternatives (TFN) from Table 7.4

Comfort			Appearance			Size			Gears			Seat			Colour			Frame		
0.7	0.9	1.0	0.7	0.9	1.0	0.5	0.7	0.9	0.7	0.9	1.0	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9
0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.1	0.3	0.5	0.1	0.3	0.5	0.5	0.7	0.9	0.7	0.9	1.0

John's scoring of alternatives (TFN) from Table 7.4

Comfort			Appearance			Size			Gears			Seat			Colour			Frame		
0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.5	0.7	0.9	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9
0.5	0.7	0.9	0.7	0.9	1.0	0.7	0.9	1.0	0.3	0.5	0.7	0.5	0.7	0.9	0.5	0.7	0.9	0.7	0.9	1.0

Step 9: Aggregated scoring Matrix using equation 7.12

Comfort			Appearance			Size			Gears			Seat			Colour			Frame		
0.626	0.828	0.965	0.559	0.761	0.932	0.500	0.700	0.900	0.559	0.761	0.932	0.356	0.559	0.761	0.422	0.626	0.828	0.500	0.700	0.900
0.422	0.626	0.828	0.559	0.761	0.932	0.398	0.608	0.788	0.000	0.247	0.472	0.171	0.398	0.608	0.422	0.626	0.828	0.626	0.828	0.965

= (0.5 x 0.5 x 0.9)^(⅓)

Alternatives final score using equation 7.13

Silverback	1.063	1.467	1.828
Pelikaan	0.882	1.301	1.670

= (0.965x0.456) + (0.932x0.544) + (0.9x0.133) + (0.932x0.164) + (0.761x0.174) + (0.828x0.209) + (0.9*0.336)

Step 10: Alternatives' de-fuzzyfied final score and rankings

Alternative	Score	Rank
Silverback	1.453	1st
Pelikaan	1.284	2nd

The Silverback bicycle is the preferred bicycle to use given the inputs from the three stakeholders

= 0.882 + [(1.301-0.882)+(1.67-0.882)]/3