DYNAMIC ADAPTIVE COST MODEL FOR WIRELESS INTERNET CONNECTIVITY IN AFRICAN RURAL COMMUNITIES

A THESIS

By

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Submitted to the Faculty of Science and Agriculture at the University of Fort Hare
In partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN COMPUTER SCIENCE

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PROFESSOR HIPPOLYTE MUYINGI

University of Fort Hare
Together in Excellence

JANUARY 2010

Major Subject: Computer Science

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DECLARATION

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Acknowledgements

Many people assisted me in the process of writing this dissertation and performing the research that led to it. My deepest thanks go to my supervisor, Professor Hippolyte N. Muyingi who provided me with guidance, encouragement, perspective, and friendship. I owe special thanks to my dearest wife Nomsa. She drew many of the figures contained in this dissertation, exercising a degree of care and esthetical judgment that went well beyond the call of duty. This work owes much to technical discussions with Professor Alfredo Terzoli, he actually suggested the topic. *Para el muchas gracias*. My profound thanks also go to Professor Jim Chadwick the Head of Computer Science Department who provided encouragement and advice throughout. I thank my lovely girl Nomagugu for helping me with the typing of a few chapters of this work. I am indebted to Nyaladzi Mpofu, Odillo Ndiweni and Ntima Mabanza, whose long standing friendships and support inspired me throughout the course. My time at Fort Hare was enriched by the friendship of many people, far too many to list here. I could not have completed this thesis without their support and encouragement. Finally, I thank my family for providing constant support and encouragement throughout my time at the University of Fort Hare. When a list of acknowledgements is compiled, it is almost inevitable that some people who deserve to be mentioned are forgotten. In the case of this work, the problem is exacerbated by the extreme length of time over which the work was performed, and the memory loss that typically accompanies old age. So, to all of you who should have been mentioned here but are not: thanks, and sorry I forgot you.

Abstract

In today's dynamic technological landscape, wireless communication networks have become an important part of economic development. The emergence of wireless technologies raises hopes to extend communication to remote areas that have not seen any tangible deployment to date. As developing nations pin their hopes to wireless technologies, cost models for wireless communication networks are becoming vital to support the emerging technologies. However, varying cost changes raise critical challenges to the estimation of both capital expenditure and operational expenditure. The network deployment process has numerous events that may cause adjustments to initially estimated project costs. These adjustments are necessary for a cost management plan and this plan includes monitoring cost performance and ensuring that only appropriate changes are made to the network project. The incidents that may cause cost changes can not be entirely predicted as their distribution tend to change dynamically from time to time. Estimating network deployment costs in such a dynamic environment necessitates cost models that can adapt to random occurrence of cost changes. Widely used cost models are usually performed by experienced personnel whose engineering experience is derived from deploying similar networks. In this approach experienced personnel add a certain percentage to the cost estimate to cater for contingency costs. Certainly such an approach depends on individual opinion, making it subjective and void of mathematical estimating relationships which are of paramount importance in ensuring that estimated deployment costs are sufficient to deal with cost uncertainties. We observe that existing approaches can only explore a limited solution space and hence can lead to cost overruns if implemented in dynamically cost changing environments. This thesis presents a wireless communication network deployment cost model that incorporates uncertainties into the final cost estimate. The model is adaptive to unpredictable cost changes since it allows adjustments of confidence levels when calculating contingency costs. This allows

dynamically updating the cost changes without the cost model being reconstructed from scratch. We make use of the Poisson process in modeling the occurrence of incidents that are responsible for causing cost changes during network deployment. We also show that the occurrence of the incidents causing cost change are random and tend to follow the Poisson distribution. Using different levels of confidence we model various cost contingencies and make sensitivity analyses to identify the probability of cost overrun when given different contingencies. The dynamic adaptive cost model can be used either at the strategic level to understand the cost of a particular technique or at the operational level, as a way to show how Poisson process in network deployment can compare with engineering experience and other estimating techniques. We believe that the model is useful for remote areas where deployment costs are volatile and the distribution of incidents causing cost change to original cost estimates are diverse and dynamically changing. Further we expect that our research improves the knowledge base of information about the costs for rural communities to connect to the Internet, consequently providing useful input to future policy debates. This work is further poised to be a utility function to help those planning internet infrastructure deployments in least developed regions.

ACRONYMS

ACWP	Actual Cost of Work Performed
ANN	Artificial Neural Networks
AP	Access Point
APIs	Application Programming Interfaces
ATM	Asynchronous Transfer Mode
BAC	Budget at Completion
BCWS	Budgeted Cost of Work Scheduled
BLDTR	Base-Level Data Transfer Rate
BWA	bandwidth access
CAPEX	Capital Expenditure
CERs	Cost Estimating Relationships
CFE	Capacity Factored Estimate
COSYSMO	Constructive Systems Engineering Cost Model
CPE	Customer Premises Equipment
CSIR	Centre of Scientific Institute of Research
DACM	Dynamic and Adaptive Cost Model
DHCP	Dynamic Host Configuration Protocol
DSM	Dynamic Synthesis Methodology
EER	Extended Entity Relationship
EHF	Extremely High Frequency
ELF	Extremely Low Frequency
EVMS	Earned Value Management System
FL	Fuzzy Logic
GRM	Grant Request Mechanism
IPsec	Internet Security Protocol
ISM	Industrial, Scientific medical band
ISP	Internet Service Providers
IT	Information Technology

KL	Kullback-Leibler
LAN	Local Area Network
LOS	Line of sight
MAC	Media Access Control
MAIS	Major Automated Information System
MAPE	Mean Absolute Percentage Error
MLP	Multiple Layer Perceptron
MLPNN	Multi Layer Perceptron Neural Network
MLS	Mean Least Square
NLOS	Non Line of Sight
NN	Neural Networks
NP	New Project
OFDM	Orthogonal Frequency Division Multiplexing.
OPEX	Operation Expenditure
p.d.f	probability density function
PAN	Personal Area Network
P_E	Probability of Error
QAM	Quadrature Amplitude modulation
QoS	Quality of Service
RDM	Regular Decreasing Monotone
RF	Radio Frequency
RIM	Regular Increasing Monotone
RUQ	Regular Unimodal Quantifier
SA	South Africa
SNR	Signal to Noise Ratio
SSs	Subscriber Station
TCP/IP	Transmission Control Protocol/Internet Protocol
UTP	Unshielded Twisted Pair
UTP LAN	Unshielded Twisted Pair Local Area Network
WANs	Wide Area Networks

WBS	Work Breakdown Structure
WiFi	Wireless Fidelity
WiMAX	Wireless Interoperability Microwave
WWAN	Wireless Wide Area Network

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CHAPTER ONE

BACKGROUND, OBJECTIVES AND METHODOLOGY

1.0 Introduction

The emergence of wireless technologies raised hopes of extending communication to remote areas that have not seen any tangible deployment to date. Such hopes are however being dampened by the slow pace of network infrastructure deployment in those areas usually perceived as economically unviable. That perception is driven by the prevalence of cost overruns in many Information Technology (IT) projects (Schwalbe, 2007). Some of the reasons of cost overruns in IT projects include failure by the project team to define well the project, failure to provide realistic duration and failure to accurately provide cost estimates.

Although the mentioned reasons for cost overruns are interdependent, cost estimation has drawn a lot of attention to researchers (Buxton et al, 1994) as they try to find efficient cost models that are capable of keeping projects within budget constraints. Cost models are dynamic frameworks that are the root of a series of cost calculations of various entities that are an integration of a process. Those frameworks are designed to comprehensively guide the budgeting process of a project. In order to keep the cost estimates within the project's budget constraints it is necessary to dynamically adjust the project's activity costs as new cost changes become inevitable throughout the duration of project deployment. Dynamic cost adjustment of the cost components unveils parameters capable of optimizing the cost model. In addition to project's cost activities, optimization of IT cost models is achieved through a careful consideration of the underlying technology (e.g. wireless or wired networks). The technology considered as part of the costing calculation should be determined by the environmental conditions as the appropriate basis for providing the project's cost structure.

The cost structure is one of the priorities when planning to deploy communication network infrastructure. The desire to improve the cost structure is motivated by the search for low cost models for deployment. This further calls for improved techniques for estimating the costs. However, deriving cost estimates is not something trivial (Pugh, 1992; Buxton et al, 1994; Meisl, 1988; Westphal and Scholz, 1997). It is inundated with uncertainties which may lead to a large estimating error. Uncertainties may emanate from the following issues (Rush et al,);

- working with insufficient information about the cost structure of the technology
- inconsistencies in previous similar estimates

- poor selection of estimating methods

The three issues mentioned above can be dealt with at different levels of the processes of project cost management.

The project's cost management processes are: resource planning, cost estimation, cost budgeting and cost control (Schwalbe, 2007). Resource planning involves the processes of determining technology, equipment as well as personnel. Cost estimation deals with approximations of all the costs for carrying out all anticipated activities. Once approximations have been made for the total costs, cost allocation is then made for individual activities through the process of cost budgeting. After the project has started, it is necessary to control the cost changes that occur during deployment. Although there is strong interaction and overlapping of the processes among themselves we would like to treat them as discrete elements. With this regard our emphasis in this work centres on cost estimation that is adaptive to the occurrence of various incidents that cause cost changes during network deployment.

It is admittedly difficult to produce an accurate project cost estimate that takes into account the risks and uncertainties capable of causing costs overruns. This thesis introduces and discusses a wireless network cost model based on the Poisson process concept. Our cost model can improve the estimation of a wireless network project's budget, including contingency and escalation costs, by taking into account risks and uncertainties. If applied correctly, the dynamic and adaptive cost model (DACM) provides a cost estimation tool that does not only forecast the range of possible costs but also the probability of those costs. In addition, the thesis discusses some of the cost estimation techniques that includes Artificial Neural Networks which is still novel in cost estimation (Harp and Samad, 1991). Although the DACM was built on the data from wireless deployments, it is an inductive cost model. It is inductive in the sense that the model is based on exact algebraic expressions (formulae). This means that it can be generalized with any other technology.

1.1 Background

Communication networks cost estimation is inundated with uncertainties associated with randomness of incidents that cause cost changes during any network deployment. It is the unpredictability of those incidents causing cost changes that hinders wireless network deployment in most developing regions of Africa. Wireless network project sponsors are uncertain of the trade offs between deployment costs and profits generated when the project is complete. Since uncertainty raises risk levels, it calls for concerted efforts to seriously consider cost estimation as a focus in order to develop cost models that provide adequate contingency costs. Contingency costs are those costs that are set aside to cover the costs that arise as a result of the occurrence of incidents that may cause cost changes to the original project cost budget. In most wireless network projects contingency costs are either over provisioned or inadequate to deal with risks resulting to cost overruns. Like all other projects wireless network projects typically carry multiple residual risks because even with risk-response actions it is hard to attain 1.0 probability of meeting cost and schedule. Each residual risk has a range of possible outcomes with associated probabilities. Trying to set aside money to cover up any risks may lead to an excessive total project cost contingency. In the following section we discuss the major processes of project cost management as well as the current trends in estimating costs for wireless network projects.

1.1.1 Present Trends in Cost Models

During network deployment significant cost changes may occur that affect cost drivers and the project as a whole. These cost change orders need to be dealt with to ensure continuity of the project and cost control. The trends in dealing with cost change orders are two-fold; funds can be sourced to cater for the cost changes as they arise or proportionally large amounts of money can be allocated. The first option is problematic as there is no guarantee that when future cost changes occur there will be money available to offset those costs. The second option allocates excess money that can eventually be used to offset cost change orders. This option is likely to unnecessarily lock up funds that can be used for other purposes. These two kinds of approaches in dealing with cost changes lack the power to unveil important effects of different cost components on the cost model. Alongside the above mentioned approaches are the two common techniques in cost estimation: the traditional technique and the engineering experience.

1.1.2 Traditional Cost Estimation

Quotes for various wireless network cost items are obtained from vendors and from historical data to get starting point estimates at the system or sub-system level of the project. The starting point estimates are adjusted based on current or recent levels of material, labour, equipment and other cost items. This becomes a base-line estimate for the total costs of the project. In anticipation of escalation of costs, an additional amount is added to each cost item this is done to allow for inflation of labour, material and equipment costs. Furthermore an additional contingency amount (often a percentage that is based on the possible risks) is added to the overall project to allow for other costs which may be uncertain and/or are beyond control such as labour disputes, scope creep, etc. The resulting estimated cost consists of the summation of the base-line estimate, escalation and contingency estimates. This total is often considered the initial cost for the project (throughout this thesis we refer to it as the original project costs). However we gain no insight on how probable it is that the most-likely or initial estimate might occur when using the traditional cost estimation technique. We also have no understanding of the possibility that the project may end up below budget and what factors are most influential in driving the project's risk. The other cost estimating technique is known as the engineering experience.

1.1.3 Engineering Experience

Cost estimation is usually performed by experienced personnel whose engineering experience is derived from deploying similar networks. Therefore network deployment costs are estimated from the known costs of a similar deployment. This is done by scaling up or down the previous costs depending on the size ration of the candidate network to the previously deployed one. Once the method of scales has been used the engineers then decide the percentage they can add to cater for other unseen cost changes. The added value is usually referred to as the contingency cost (Thompson and Perry, 1992). In cost estimation contingencies ensure that the estimated deployment costs are sufficient to deal with uncertainties. However, adding percentages as cost contingency is inherent with several weaknesses (Thompson and Perry, 1992):

- The percentage added may not be appropriate for that specific deployment because it is arbitrarily arrived at.
- The percentage added gives a single figure prediction that is not justified.
- It also does little to encourage creativity in estimating practice; and can lead to a routine which can propagate oversights.

The selection of the scaling factor and the percentage adjustment is arbitrary and solely depends on the opinion of the engineers. This arbitrary selection is not based on concrete evidence hence engineering experience renders cost contingencies far from long range strategic goals for sensitive analysis. Furthermore deriving deployment costs in this manner may lead to the project being over budgeted. Figure 1.1 shows typical examples of IT projects sizing problems (Huang, 2007). In the Figure sizing problem 1 represents a category of IT projects that are abandoned or pursued to completion. Sizing problem 2 represents the category of projects that fail because of operational issues or succeed. Sizing problem 3 represents the category of projects that are over budgeted or within budget. Figure 1.1 shows that 43% of IT projects are usually over budgeted (at least 4 out of every 10 projects). This is a very considerable percentage and it is not cost effective as funds are unnecessarily locked instead of being channeled to other areas that may need development.

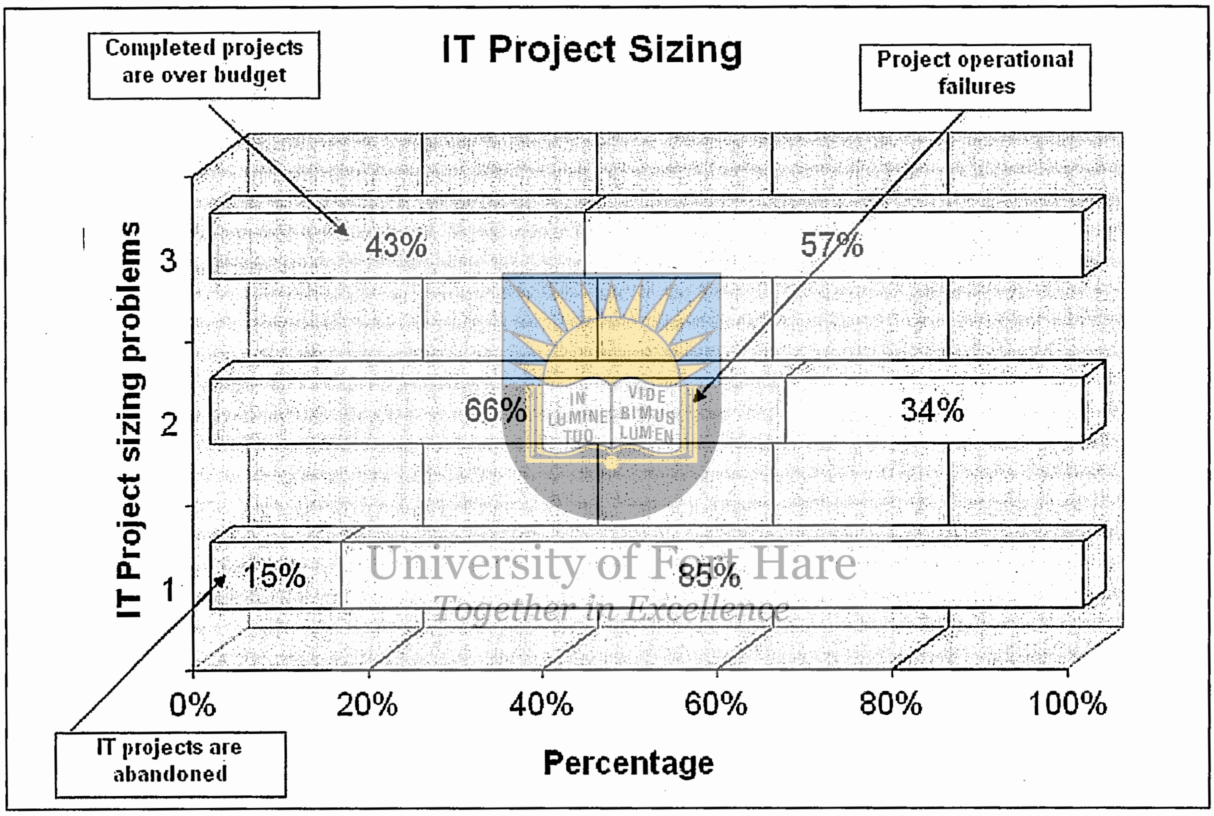


Figure 1.1: IT Project sizing problems (Huang, 2007)

The other 57% consists of projects that fall within their budget plus those that are under budgeted. The proportion of the over budgeted projects to those that are within budget further underscores the gaps that exist between the available cost estimation techniques and the accurate estimated projects budgets.

1.2 Definitions of Theoretical Terms

Model

This term's definition depends on the context at hand. A universal definition refers to a model as a hypothetical description of a complex entity or process. In this research we consider a model to be a theoretical construct that represents Internet deployment processes by a set of variables and quantitative relationships between them (Wikipedia /ECO, 2006).

Dynamic Model

We use this term to refer to a change of state in response to changing variables as opposed to steady-state models.

Uncertainty

There are a number of definitions for this term, in this work it refers to a failure to know anything that may be relevant for providing an accurate project cost estimate, such as future variables or details of a technology changes.

Confidence Level

Confidence Level is the likelihood of some event occurring expressed as a percentage.

Cost Change Orders

We refer to cost change orders to cost adjustments that occur to a project's initial cost estimates. We also use this term interchangeably with change order costs.

Contingency Costs

Contingency costs are funds that are reserved for any cost changes that can affect the total costs during the implementation of a project. It is necessary to have contingency costs because uncertainty exists in the estimating data and assumptions. The amount of contingency which is required is a function of the desired probability that the final wireless network project cost will not overrun the estimate.

1.3 Problem Statement

The most outstanding problem in deploying wireless technologies in rural areas is the trade-off between deployment costs and profit margins. Uncertainties surrounding the total deployment costs do not help either. Organisations that are potential funders of rural network deployment require project proposals upfront to assess the viability of committing their resources. However, the trend is that when making proposals estimated costs are either inflated or fall short of the required amount. If the deployment costs are inflated, a lot of resources are unnecessarily tied. If there is underestimation then from time to time the project team will have to ask for more funds and this is very embarrassing to management team as it shows poor planning. The cause for all this is the continuous use of traditional estimation methods for projects' capital costs. Central to traditional methods of estimation is the engineering experience which has been discussed briefly in Section 1.1.3. Costs are estimated based on past similar projects and this usually leads to estimation error and bias. A number of researchers have identified bias in cost estimation (Mak and Raftery, 1992; Raftery, 1994). The error appears when there is a deviation of the actual costs from the estimated costs. When the error has a mean that is different from zero it then becomes a bias. The estimation methods that are prone to errors and biases are unable to deal with uncertainties that are associated with network deployment cost models, especially deployment in remote environments.

There have been efforts by some researchers to address the error problem; such efforts have brought about fuzzy analogy and Artificial Neural Networks (ANN) as new techniques for estimating project costs. Of course there are more other techniques (those are discussed in Chapter 3) but these two are central to cost error minimization. Fuzzy analogy eliminates subjective judgement (a limitation of engineering cost estimation method) through its ability to use categorical quantifiers to deal with linguistic quantifiers. The ANN minimizes the cost estimation error by using a dedicate algorithm to train the neuron to respond to different new situations given various cost inputs. Detailed discussions of both the fuzzy analogy and the ANN are found in Chapter 3 of this thesis. Despite their complexities and abilities to minimize the project's cost function errors, the two novel cost estimation techniques have notable limitations that our cost model addresses. Fuzzy analogy fails to deal with uncertainties caused by the dynamics of cost changes during project deployment. The ANN on the other hand gives less benefit in terms of sensitivity analysis of the relationships between inputs and outputs. Sensitivity analysis gives the opportunity to explore effects of various parameters on the cost function thereby allowing for proper monitoring of the main outputs of the cost estimating process. This helps to determine the "cost baseline, project funding requirements, requested changes and updates to the cost management plan" (Schwalbe, 2007: 267). The wireless network cost model proposed in this thesis addresses the problem of cost uncertainties and allow for sensitivity analysis. It addresses these problems by applying the Poisson process in responding to aims and objectives set out in this thesis.

1.4 Aims and Objectives

This research sets out to define the extent to which probabilistic methods can be used to overcome the challenges associated with cost estimation of wireless network projects. We aim at building an adaptive cost model for wireless Internet connectivity.

Main Objective

The overall objective is to provide a framework to estimate the total costs of deploying wireless network infrastructure using the Poisson process.

Specific Objectives

We expect that the findings of this research provide an opportunity to:

- Ascertain the cost structures of wireless network deployment.
- Understand the nature and costs that are directly associated with wireless network deployment.
- Build an augmented theory derived from resource usage in wireless network deployment.
- Develop wireless network deployment cost model, with a focus on providing adequate contingency costs.
- Present quantitative results based on the case study.
- Identify further areas that need research in an effort to improve wireless network cost estimation.

1.5 Research Questions

This research was developed with the view of addressing the following questions:

- How has the wireless network deployment been approached in general? This question was addressed by reviewing literature on the deployment of wireless networks and considering examples of different technologies
- What are the system elements and factors for costs and what is the nature of their interrelationships and complexity for estimating initial wireless network project costs? The underlying complexities were unearthed by considering cost drivers and observing their effects on the deployment process.
- Can we build a cost model for wireless network infrastructure deployment that adequately provides for contingency costs? This question was addressed by constructing our cost model using the Poisson process approach.
- Which cost parameters are fundamental for an optimal wireless network cost model? This area was addressed by carrying out sensitivity tests on the proposed model to reveal the trends of changing parameters and the best optimal solution.

1.6 Scope

The purpose of the DACM model is to serve as a tool for estimating wireless network project costs for rural and semi-rural areas with a guarantee of providing adequate contingency costs. Although the model can apply to projects to be deployed anywhere, model parameters were specifically derived from projects deployed in rural areas in South Africa. Our cost model considers only those cost drivers that have a substantial cost effect on the total costs in the context of studied projects that provided empirical data. This research produces a proposed wireless network infrastructure cost model and derives working assumptions and technical scenarios for deployment of wireless Internet network infrastructure.

1.7 Justification

While some work on cost models have been accomplished, little progress has been made relative to cost estimation which establishes contingency levels for meeting optimal budget. Changes in network infrastructure deployment costs occur from time to time and such occurrences tend to be discrete. They also tend to cause costs overruns which may seriously affect the deployment stages. Hence beside initial projected deployment costs, cost changes over time deserve more attention from the research community. In view of cost variations, our model incorporates a Poisson process method to estimate the expected total costs closely to the actual.

Estimating costs for network deployment is challenging because of variations in equipment costs and a number of unexpected scenarios involving deployment. The usefulness of cost estimation is to give a reasonable estimation that allows the construction of scenarios for the future while reflecting the reality on the ground. There is need for a robust cost model with adequate functionalities that adapts to costs variations.

Cost estimation has been driven by unreasonable biases and expectations in the past. Further more the process of estimating costs involves numerous unknown parameters and this makes the processes even more complicated. For matters of drawing up a budget for network deployment the concern is how would we come out with an estimation that will not result to cost overruns and probably with minimum errors? Figure 1.2 shows expected error range at various stages of developing cost estimates for an Internet technology project. As we can see this is typical to engineering estimate where by cost estimates for initial stages of the deployment experience the worst range of expected accuracy. This is because the estimation is based on opinion and liable to underestimation of contingency levels of kick starting the project. As shown in Figure 1.2 the expected error range improves as the engineers learn cost change trends during the implementation of the project. The figure further shows that even at a point of best range accuracy, the expected error is close to 10%. The focus of cost estimation is to try and eliminate estimation errors hence the necessity of providing a robust cost model that encapsulates adequate contingency costs.

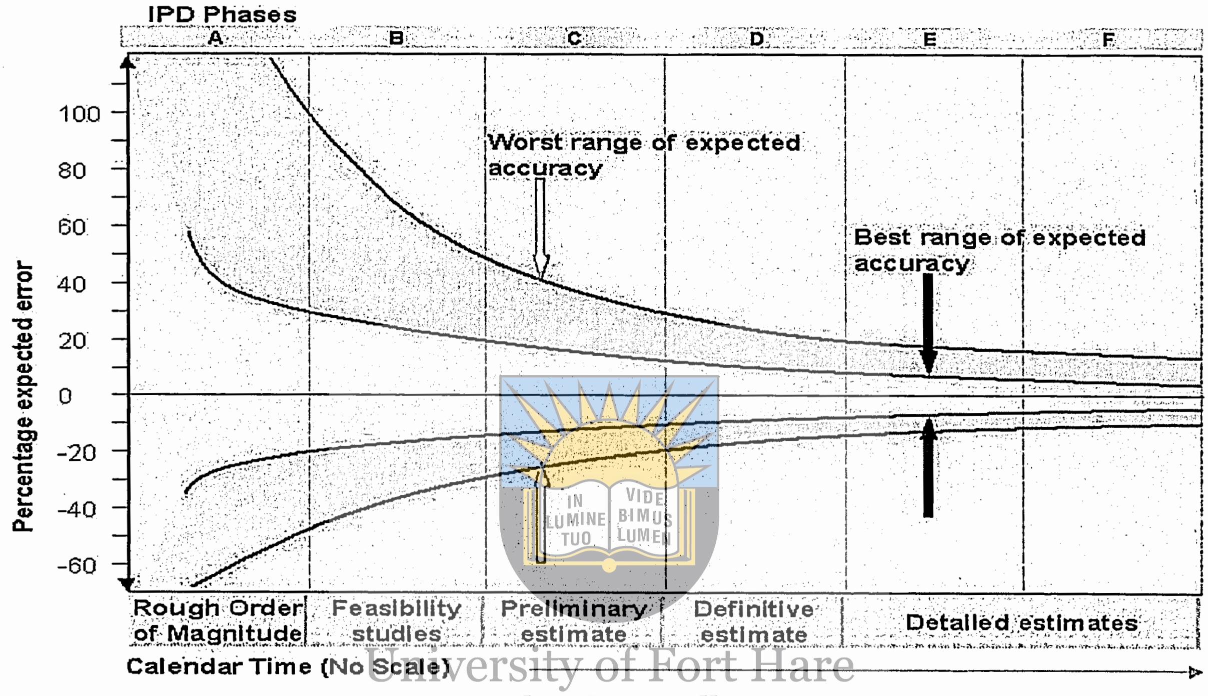


Figure 1.2: Expected error range of estimates (Huang, 2005)

1.8 Importance and Contributions of this Research

Wireless network is necessary for the rural development and cost models that are accurate on wireless technologies are a step towards achieving this. The proposed model in this thesis can be used either at the strategic level to understand the cost of a particular technology deployment or at the customer level, as a way to show how Poisson process in wireless network deployment can compare with engineering experience and other estimating techniques.

The main contribution of our research is the development of an adaptive cost model framework for providing adequate contingency costs for wireless network projects. The model handles uncertainty costs through the use of the Poisson process. The proposed cost model further allows sensitivity analysis. The research also helps to identify other research problems for future work. We also expect that this research improves the knowledge base of information about the wireless network costs and cost estimation techniques. This work is further poised to be a utility function to help those planning wireless Internet infrastructure deployments in least developed regions. With the results from our research one can derive several guidelines on designing probabilistic cost models.

1.9 Methodology

In this section we outline procedures we undertook while we developed our thesis. Our overall approach to developing this thesis embraced dynamic synthesis methodology. Dynamic Synthesis Methodology (DSM) ensures a holistic approach to any research giving it a wide range of methods and tools.

1.9.1 Dynamic Synthesis Methodology

Dynamic synthesis methodology has recently become a powerful research tool. The methodology derives its power from its ability to harness all theoretical concepts of a process and its response to different inputs over a period of time. The outputs also serve as feedback on the input function variation. There is a mix up at times about dynamic synthesis methodology (shown in Figure 1.3) and system dynamics method. The latter which is very popular, is actually a phase in the former. This was demonstrated by Albin (1997) and in our

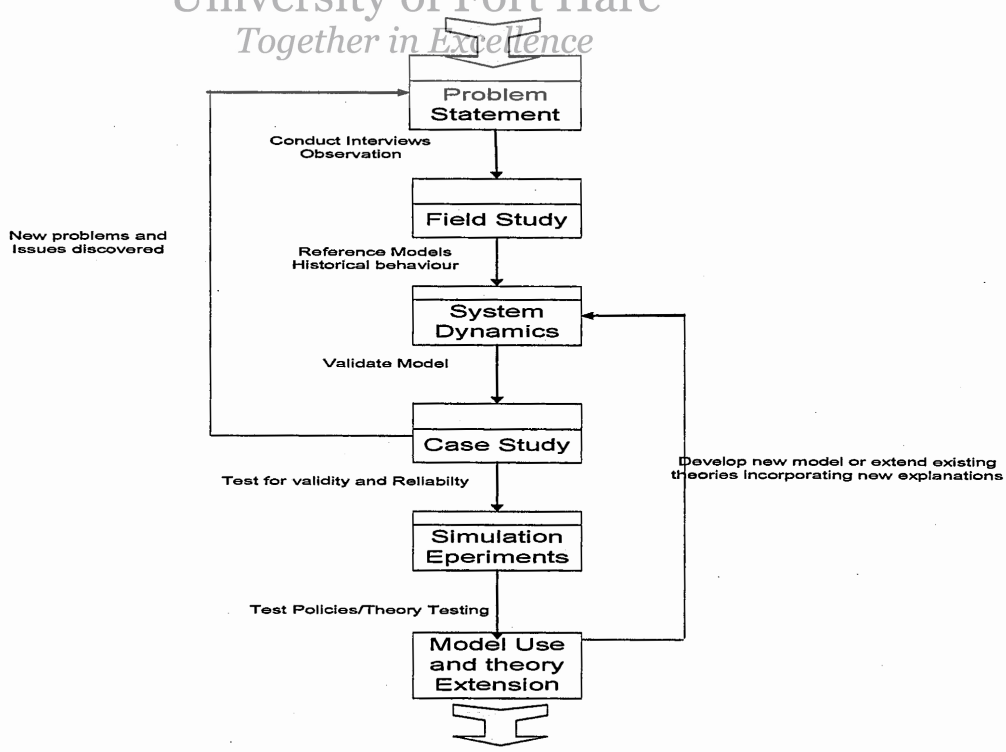


Figure 1.3: Dynamic Synthesis Methodology
Adapted from (Luna-Reyes, 2003)

research we also used system dynamics within the context of dynamic synthesis methodology. System dynamics enabled a sound understanding of complex (Luna-Reyes, 2003) systems revealing how the inputs affected the outputs and vise versa. We also adopted the case study approach in our work. The inclusion of the case study (qualitative) (Albin, 1997) method within dynamic synthesis methodology (quantitative) increased the probability of robust and clear conclusions. Figure 1.3 shows a flow chart of our approach based on dynamic synthesis methodology. Below we show various activities we carried out in each phase ranging from problem statement to model use and theory extension.

1.9.1.1 The Problem Statement

The problem statement stage involved our focus on the constraints of the problem as we narrowed down the problem to manageable levels. At this stage we also focused on revealing salient features of the problem and established variable relationships in general. We identified and discussed the problem and considered what has been done previously to address the problem. We also outlined reasons why previous endeavours have failed to address the problem. We further outlined our plan towards the solution of the problem. Having identified the problem we then engaged into a field study.

1.9.1.2 Field Study

One of our primary tasks was to research on cost estimating parameter relationships. Those parameters were gathered from historic information on similar technological deployments. The collection of data has actually been a preliminary method for research for centuries (Luna-Reyes, 2003). We investigated the background of our research and then collected the data that we needed. This involved archival research (Luna-Reyes, 2003) studying the existing literature on the problem and making notes on issues that were important for our cost model. We obtained most of our data on wireless network deployment from one of big telecommunication companies in South Africa.

1.9.1.3 System Dynamics Phase

This phase involved a lot of sub-phases which are explicitly explained in (Albin, 1997). System dynamics uses causal loops that consist of arrows connecting variables or instances in a way that shows how one variable or instance affects another. Each arrow in a causal loop is labeled with an "s" or an "o" (Albin, 1997). An "s" means that when the first variable or instance changes, the second one changes in the same direction and an "o" means that the first variable or instance causes a change in the opposite direction in the second variable or instance (Albin, 1997). The arrows come together to form loops, and each loop is labeled with an "R" or a "B." "R" means reinforcing; i.e., the causal relationships within the loop create exponential growth or collapse (Albin S., 1997). A "B" means balancing; i.e., the causal influences in the loop keep things in equilibrium.

As shown in Figure 1.4 understanding the problem made us to be able to define it. After we identified the problem it further enhanced our understanding of the problem, in other words the output of model understanding became an input to problem definition whose output was also a feedback to model understanding.

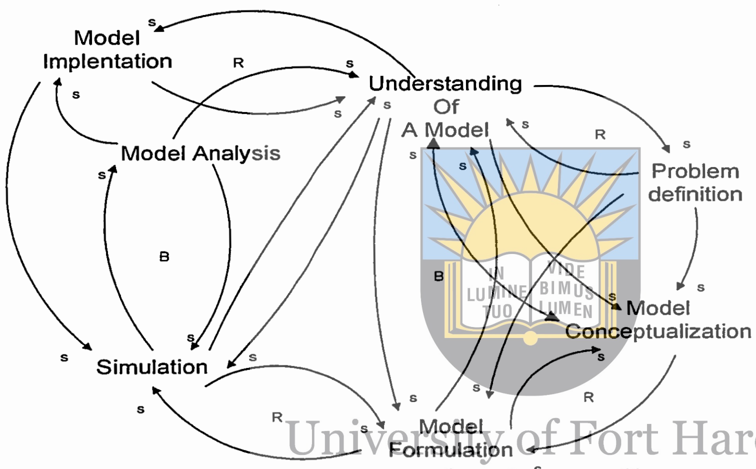


Figure 1.4: System Dynamic Modelling process (Adapted and modified from Albin, 1997)

The direction of the arrows in Figure 1.4 indicates a flow of an output from one end and serving as an input on the other end. So we notice that feedback loops were formed in this kind of research approach. The loops were iterative through out our research each time producing a refinement of model understanding, model conceptualization, model formulation, simulation, model analysis, problem definition and model implementation. Model conceptualization took long as we tried to formulate the cost model.

From the literature review (field study stage) and data collection we conceptualized (Albin, 1997) the wireless network cost model. At that stage conditions describing the cost model were assembled (Model economics, 2001) in a systematic manner showing low level and high level constraints of the wireless cost model. We categorically described also the assumptions under which the model was developed. Although it is arbitrary that one approaches conceptualization, we chose to follow the four steps of conceptualization according to Albin (1997), the first step was to define the purpose of the model, secondly to define the model boundary and to identify key variables, and thirdly to describe the behaviour of the DACM by drawing reference models of the key variables. Details of these steps can be found in (Howard J, 2001). A considerable number of conceptualization mapping tools (Albin, 1997) have been developed. These as described by Reyes (1993), include flow charts, network diagrams and many others. We used hybrid diagrams, stock-and-flow diagrams, and network diagrams to conceptualize our cost model.

1.9.1.4 Case Study Phase

The case study approach has been in use for a very long time, dating back to the early part of the 20th century (Case study approach, 2005). The case study approach was previously a domain of sociological and psychological investigations (Case study approach, 2005). It later spilled into scientific research and was quickly integrated with other scientific methodologies.

To get an initial insight into the estimation of deployment costs, we surveyed already deployed wireless systems. The DACM was then constructed by drawing parameters from the case studies. In our work we studied a number of other wireless network deployments. The case studies consisted of 18 wireless network projects obtained from a renounced communications company in SA. From a pool of 18 different wireless network projects deployed in semi rural and rural areas we managed to make use of 8 projects and discarded 10 as those either had a lot of missing information or the deployment time was too short to allow for any considerable number of cost change orders. The data obtained was then used to calculate inputs for our model for example number of incidents causing cost adjustments, the cost of change orders, and the mean of the cost change orders as well as its standard deviation.

Our data consisted of the costs incurred during network deployment. These included **Planning and Design costs** (which were made out of *Infrastructure design and RF design costs, consulting and requirements analysis costs and the project management costs),* **Network Infrastructure** costs (these costs were made up of n*etwork installation costs and cabling costs),* **The Hardware Costs** (consisted of *Access Points' and Controllers' costs),* **The Wireless Installation Costs** (were made up of *Wireless certification costs which were* incurred as a result of giving network support staff training in areas such as network applications, network engineering, and hardware as well as network security), **User training**

costs and the **Go live support costs** (which were incurred as a result of supporting and optimizing the operative system, technical infrastructure and load distribution as well as the network's business process. Also included in go live support costs were documentation costs, costs for maintenance contract, and costs of training manuals that can be used to quickly train end users and included customized standard operating procedures). The other costs considered were the **Management Installation** costs (made up of *management tool installation*, and *wireless integration costs*). A detailed discussion of the above components costs is found in chapter five of this thesis. The technologies that were used in deploying various networks considered in this study were the WiMAX IEEE 802.16 and WiFi IEEE 802.11 standards. Two of the studied networks were the converged WiMAX/WiFi networks, the rest were either WiFi or WiMAX providing last mile connectivity. The networks' coverage areas varied from a radius of about less than a kilometre in a single institution (e.g. a school) to a radius of about 5km connecting different schools.

1.9.1.5 Simulation Experiment

The prior data evidence was used to generate our cost model parameters to enable the potential assessment, analyses and forecast on the impacts of changing cost parameters and applying different levels of confidence on contingency costs. A MATLAB routine was then created and brought about a formidable cost model that revealed the interactions between observed cost variables. As with other models validation is very important, the generate test which is a validation technique involving experimenting with different inputs to determine the variations of the model results was applied.

1.10 Model use and Theory Extension

The integration of case study into our methodology helped to extract real features and trends of the cost model. This included the response of the cost model to variability of various contingency costs. Manipulation of those trends through other phases of the DSM enabled the building of comprehensive theories and extensions of wireless network deployment cost models. Using analysis of experiment results provided a mathematical account of the properties of wireless network cost models. Such properties also revealed the cost model usability and its cost effectiveness. The rest of the chapters are outlined in the following section.

1.11 Thesis Outline

CHAPTER 2: WIRELESS NETWORK DEPLOYMENT AND COST ISSUES

The cost structure of communication networks (the wireless in particular) is fundamental to the construction of a dependable cost model. In chapter two we discuss wireless networks mainly focusing on cost drivers of network deployment. We also discuss the basic deployment principles and discuss in detail various wireless technologies.

CHAPTER 3: GENERIC COST MODELLING FRAMEWORK AND RELATED WORK

In this chapter we discuss various cost modeling constructs and different techniques used to build cost models. Those techniques included are; expert judgment, method of scales, parametric methods, analogy methods, fuzzy analogy estimation methods, Artificial Neural Networks estimation methods, engineering methods. We also discuss previous works by others that inspired us in our work.

CHAPTER 4: STATISTICAL ANALYSIS AND THE POISSON PROCESS IN MODELLING COSTS

In our work we used Poisson Process to estimate deployment costs factoring in contingency costs that arise as a result of cost change orders during network deployment period. This chapter discusses underlying theory of the Poisson process. We also included use of statistical analysis in cost models as this is the measure of success against which we test the validity of our cost model.

CHAPTER 5: THE WIRELESS NETWORK DEPLOYMENT FRAMEWORK

In this chapter we present the wireless network deployment framework. In our approach to the framework model we designed reference models that encapsulate cost parameters and their interactions. The reference models are discussed in this chapter and they include the planning and design costs, wireless hardware costs, network infrastructure costs, wireless installation costs and management costs.

CHAPTER 6: RESULTS

The input values and statistical parameters useful to the cost model are calculated in this chapter. Sensitivity tests on various parameters of interest are carried out and explanations are offered. Every cost model has its own limitations; this chapter also discussed the limitations of our cost model.

CHAPTER 7

To conclude our work we discuss what has been achieved and a summary of all the chapters. The chapter also presents possible future extensions of this thesis.

1.12 Conclusions

This chapter presents our research by setting out the objectives and the scope of the research. A background of the research is given and the justification for carrying out our work is explained. The problem has also been stated to help give a direction of our research. Any research is not purposeful if it does not make any contributions to the knowledge base; we have described the contributions of the research and its importance.

We have mentioned the present trends in cost estimation mentioning the common methods used. These include traditional methods, engineering experience, fuzzy analogy and ANN. Traditional methods are unable to minimize errors because of their failure to accurately anticipate uncertainty costs. The engineering experience tries to use the experts' experience on deploying wireless networks but this also is liable to human bias. We have also discussed the power of fuzzy analogy methods in dealing with linguistic quantifiers. Fuzzy analogy also eliminates bias emanating from human judgment. The ANN minimizes cost estimation error through the use of certain algorithms that are applied to train the neuron. The training continues iteratively until a certain level of confidence is reached. The ANN however provides little opportunity to carry out sensitivity analysis that will allow making of appropriate conclusions.

To construct a cost model one has to first understand the cost drivers of the technology to be used; in the case of this thesis the technologies are wireless fidelity (WiFi) and Worldwide Interoperability for Microwave Access (WiMAX). The two wireless technologies are discussed in detail in the next chapter. We also consider basic wireless network deployment principles and environments for instance Line of Sight or Non Line of sight deployment.

CHAPTER TWO

WIRELESS NETWORK DEPLOYMENT AND COST ISSUES

2.0 Introduction

The majority of people in developing countries still live in rural areas with dire need of communication network infrastructure deployment. Deploying network infrastructure in those areas is however an arduous task throttled by various hurdles that include spectral regulations, the three cost processes which are; total cost estimation, budgeting and controlling costs, rough terrain and low population densities. Because of those hurdles, cable lines are out of consideration, as their present coverage area is limited to urban and semi-urban areas and cannot span vast rural areas because of their intensive capital requirements. The developmental needs of various communications can be met through technological innovation that makes universal access (Best, 2003) affordable to the whole population. An inclination has been towards wireless networks. Although seen as disruptive technologies in most developed countries, wireless Internet networks are destined to be the most viable solution for last mile connectivity in rural areas of developing countries. Their composition "…consists of several components that support communications using radios or light waves propagating through an air medium" (Geier, 2000). This makes wireless network deployment even more suitable for areas with challenging geographical conditions which render wired networks not viable option. The full potential of using wireless Internet networks to extend connectivity in rural areas remains a vibrant innovation. It is however the slow pace of network deployment that is worrying. The uncertainty about the overall costs of deployment in new and previously unexplored environments deter potential project sponsors. Cost estimation still largely relies on network engineering experts who have negative opinion on unexplored areas like rural regions. Wireless technologies like WiFi and WiMAX possess attributes that when combined with good cost estimating models would encourage roll out of communication networks anywhere.

The goal of this chapter is to discuss the innovations motivating wireless network deployment in rural areas. The promise of wireless is not without constraints; we briefly elaborate some of them and make a review of common wireless technologies that are fundamental to any rural wireless Internet deployment. WiMAX is becoming an attraction in rural because of its range and ability to propagate both on Line of Sight (LOS) and on none line of sight (NLOS). This makes WiMAX a very promising technology for rural cost models. We therefore include a detailed discussion about WiMAX in this chapter. The chapter also has a discussion on the cost structure of wireless Internet network deployment and the determinants for selection. We sum up this chapter by drawing a number of conclusions about wireless technologies and their resultant cost models.

2.1. Challenges and Motivations for Wireless Networks

2.1.1. Critical Innovations Motivating Rural Wireless Networks

For any technological development, there are three phases of evolution as noted by Hughes (1992); intervention and innovation, transfer and growth as well as consolidation. The deployment of wireless networks is in the second phase in most developing countries. This phase involves uncoordinated pilot projects in different geographical areas. Parallel to the transfer and growth phase are concerted researches that are directed to probe various architectures of wireless networks that are destined to cost-effective developments.

Best (2003) underscores three critical innovations that can motivate the successful deployment of wireless technologies in rural communities. These are; the new and low-cost technologies, micro and small enterprises that provide locally tailored value-added services and supportive public policy. The interaction of these innovations forms what is known as system dynamics which is represented in Figure 2.1. The figure shows that supportive policy promotes deployment of new and low cost technologies. The positive feedback is improved public infrastructure and the creation of more conditions to further support other public policies. Positive feedbacks are known as reinforcing dynamics (Sastry, 1998) shown with a loop R in Figure 2.1. To micro and small enterprises the technology innovation provides as positive feedback; the platform for the support of locally tailored services. The technology innovation itself receives as reinforcing dynamics; a conducive environment that promotes low cost network infrastructure deployment. Micro and small enterprise innovation act as a catalyst to pervasive connectivity. It is these positive feed backs to each critical innovation that drive rural areas to seek reliable and affordable Internet deployment cost models to build their competencies. In sections 2.1.2, 2.1.3 and 2.1.4 we briefly describe three critical innovations that motivate rural wireless network deployment models.

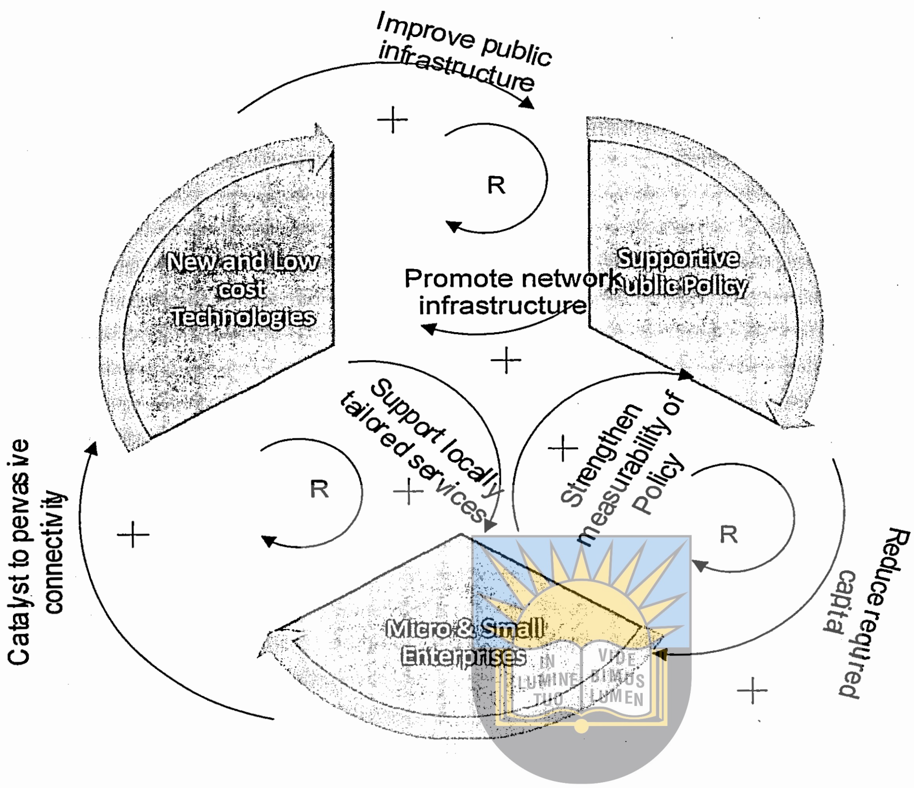


Figure 2.1: System Dynamics of Rural Wireless Deployment innovations (Adapted from Best, 2003).

2.1.2. The New and Low-Cost Technologies

Wireless technology has migrated from complex hierarchical voice-oriented architectures to low latency and all-IP based designs, reducing complexity. Furthermore, the cost component representing electronic equipments is shrinking due to new advances in microelectronics, which by Moores Law (Boy and Dieter, 2006) provide more functionally at lower cost and size. Research has shown that wireless access technologies are being embraced by everyone because of their ease of installation, low cost, and high bandwidth (Corderio et al, 2003).

2.1.3. Micro and Small Enterprises

The existence and promotion of micro and small enterprises serves as a catalyst to deploy communication networks. The provision of wireless connectivity would promote locally tailored services that will ensure relevance of services to the community. We can refer to the Dwesa[1] (SA) project where local women are now able to market their beading wares online because of a wireless network that was deployed using WiMAX and WiFi. The existence of wireless network in that area has opened new markets for the locals.

2.1.4. Supportive Public Policy

Policies that unilaterally create conditions that promote network infrastructure development are a motivation to the success of pervasive connectivity hence aggregating demand. A deliberate policy to deploy and aggregate demand should include spectrum license exemptions (Best, 2003). Most developing countries have embraced the policy of free license spectrum within 2.4GHz band. This encourages deployment of wireless networks in remote areas that were previously neglected.

2.2. Overcoming Existing Constraints

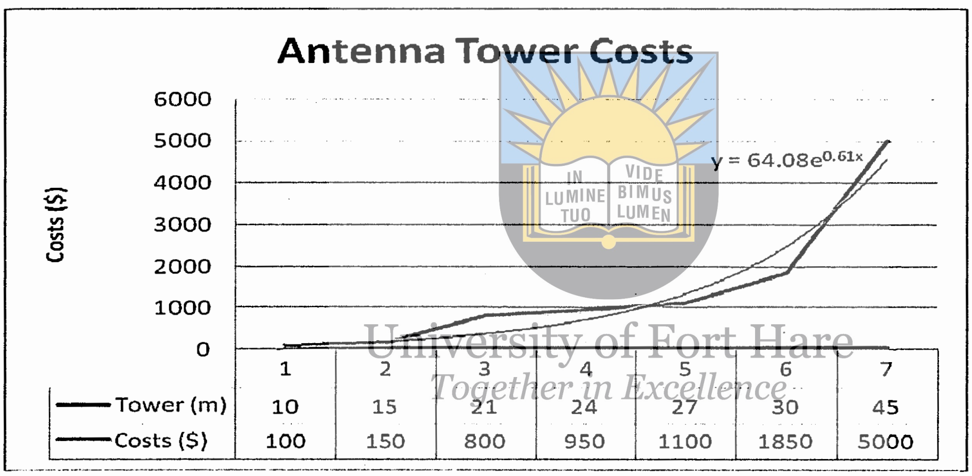
Although wireless technologies occupy the exponential growth in the network deployment space a number of constraints still exist. These include infrastructure and installation costs. Not withstanding the fact that there are no tall buildings to pose as inter-link constraints (Sayandeep and Bhaskaran 2007) in rural areas, the existence of mountains and location of some villages in valleys can still pose a great challenge in designing a wireless infrastructure cost model. The dominating factors in wireless network infrastructure cost emanate from physical deployment of infrastructure such as planning, installation of antennas and towers, and equipment. The costs of towers can contribute substantially to the total cost of network deployment if we consider possible inter-link interference by big mountains. Table 2.1 shows different tower heights and their various costs. Although the metal composition of a tower and its density would contribute to its cost, the costs generally increase with height.

*Table 2.1: Antenna tower costs (*Geier, 2000)

Tower (m)	10	15	21	24	27	30	45
Costs ($)	100	150	800	950	1100	1850	5000

[1] Dwesa is a rural area separated by the Mbashe River and spread across two adjacent coastal districts of southern Transkei (SA). The university of Fort Hare in conjunction with Rhodes University have deployed a wireless network and have implemented a number of e-commerce projects to help poor communities.

Figure 2.2 shows the increase of antenna costs with increasingly varying height of the antenna tower. The trend-line reveals that costs of antenna tower increase exponentially as the height increases. This increase is sharp when the height is 30 m or more. Ideally up to 60 m may be required in some areas. This means that antenna tower costs can be a serious constraint for low cost models for rural connectivity. However some deployments are carried out where there is already existing tall building infrastructure like schools and universities. In that environment the height of the antenna tower will be minimal thereby reducing the equipment costs.



	1	2	3	4	5	6	7
Tower (m)	10	15	21	24	27	30	45
Costs ($)	100	150	800	950	1100	1850	5000

*Figure 2.2: Trend-line of Tower Cost versus Tower height (*Geier, 2000)

The cited constraints can be overcome through various ways in rural areas. Costs that are associated with installation can be minimized by having a team of volunteers from experts and the community to help put up the network at minimum labour costs. Organizations and individuals can donate some of the equipment including tower antennas. When weighting cost variables with such interventions, the resultant deployment cost models would be fairly attractive for rural regions.

While it is desirable to have cheaper equipment, the focus should shift to reducing the total system costs. Such an endeavour would require concerted efforts in developing innovative cost models that would accurately estimate total system costs based on low cost wireless technologies. Cost estimation in that regard should include mechanisms to deal with unexpected cost variations during infrastructure deployment.

There are different types of wireless networks whose diverse architectures and capacities influence the deployment costs. The general architecture of a wireless communication network is shown in Figure 2.3. This general architecture is important in determining the design of a wireless network. The decision for example to select the type of antenna will affect the deployment costs. Interference can be overcome by using technologies that employ mechanisms that deal with noise or interference for example Orthogonal Frequency Division Multiplex (OFDM) in the case of WiMAX; this will be described in detail later in this chapter.

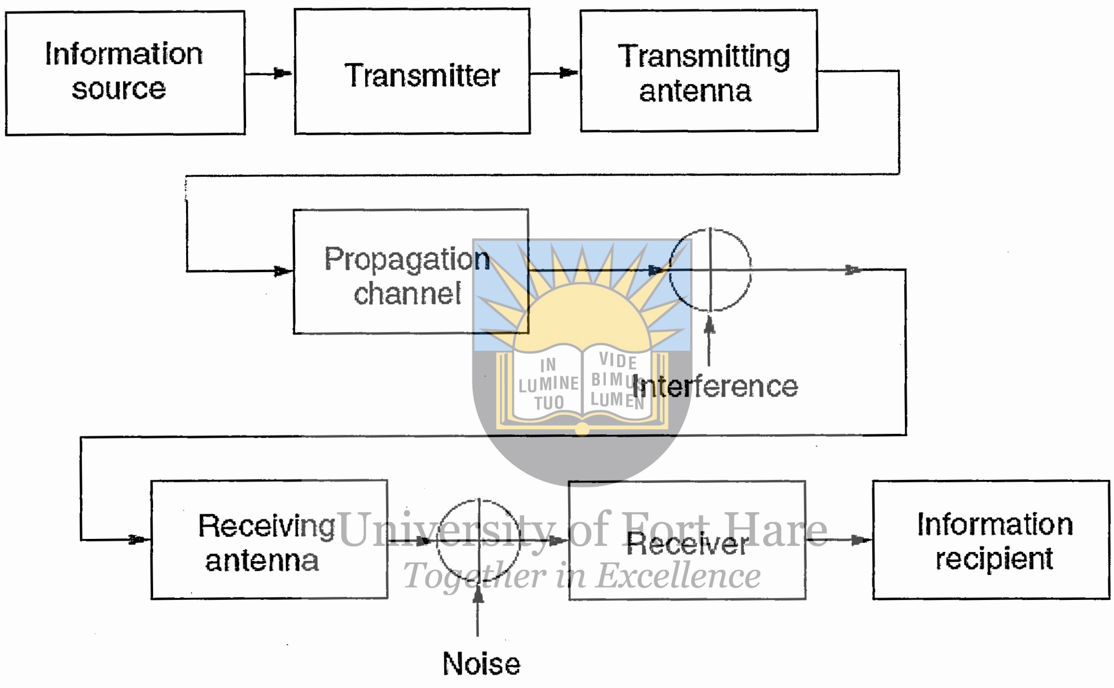


Figure 2.3: Wireless Communication infrastructure architecture (adapted from Geier, 2000)

2.3. Wireless Network Deployment Technologies

Wireless networks can generally be categorized into three groups: Personal Area Networks (PANs), Wireless Local Area Networks (WLANs) and Wide Area Networks (WANs). Deployment costs vary according to the technology used. A primary goal of any wireless LAN deployment is to provide reliable signal coverage and expected level of performance (bandwidth capacity) at all desired locations. The goal of this section is to give a brief description of the three popular network deployments. We identify different characteristics that make them suitable for different coverage and therefore their preferences in different environments.

2.3.1 PANs

This type of wireless networks provides connection within a few meters from each other, only a range of up to 10 metres. The technology in this arena is the Bluetooth (Bialoglowy, 2005). Data rate offered by PAN is slower than WLANs. The limiting factor on wireless networks is the distance versus bandwidth, as you move away from the access point, data transfer rates diminishes.

2.3.2 Wireless Local Area Networks

WLANs cover a local area which can be a university campus, a school or a building block. WLANs offer the opportunity to manage own network and use low cost infrastructure. These networks usually support data rates of up to 54Mbps and can extend connectivity to a radius of about 100m (ISS White Paper, 2001). Some of the advantages offered by WLANs include mobility, scalability, simplicity and the installation costs are considerably lower than that of wired networks. However WLANs may compromise security. Details of security issues of WLANs can be found in various sources including in (ISS White Paper, 2001). The WLAN architecture is shown in Figure 2.4.

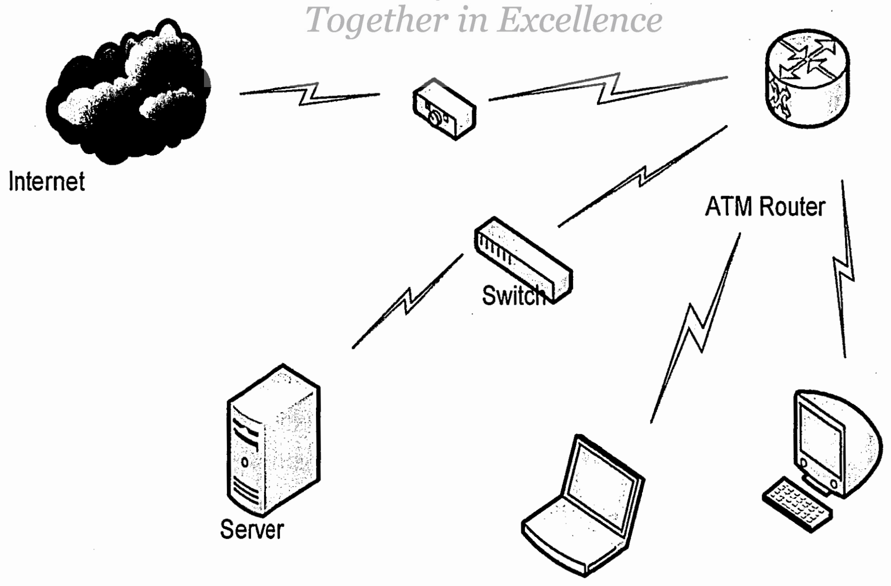


Figure 2.4: Wireless Local area network architecture

2.3.3 Wireless WANs (WWANs)

WWANs are characterized by their geographical coverage. Their coverage is relatively large compared to the other categories. WANs generally utilize different and much more expensive networking equipment than do LANs. Further more their demand for security is high especially when using licence free spectrum. While unlicensed spectrum provides huge cost savings to users it has a problem of denial of service attacks (DoS). To deal with the DoS and other security threats a number of security measures need to be put in place, this however increases network costs. There are a number of features of WWANs and security measures which are not part of our discussion here, however a detailed description can be found in (Unger, 2003). In the following section we discuss the benefits of wireless networks.

2.4 Benefits of Wireless Networks

Wireless networks circumvent the arduous task of running cables across the walls to network devices. It can be difficult and time consuming to install Ethernet cables from each device to another. The major benefit of wireless connectivity is extremely low initial costs (Wireless Community Networks, 1999) and operational costs. There is also easy of implementation, and effective Base-Level Data Transfer Rate (BLDTR) (Wireless Community Networks, 1999). Through the use of LANs, ad hoc networks that can be formed provide convenience and mobility. Also the wireless networks can offer high speed data links of up to 54Mbps and enables fast installation of baseline stations. The layered design of this type of networks allows direct use of application layer software developed for wired networks.

2.5 Disadvantages of Wireless Networks

Although wireless communication networks provide a wide range of benefits, they also have limitations. Firstly, they may suffer from dead spots. These are areas with the presence of AP, but unable to receive communication signals because of some physical obstacles. Reflections from different obstacles can cause signal distortions, as signal bounce, they take a longer route and arrive out of phase from the direct path. Some limitations that can be considered are: radio interference, weather and accidental damage and throughput.

2.5.1 Radio Interference

When multiple radio antennas are located in close proximity, signals may interfere with each other causing retransmission of signals and loss of throughput. To avoid interference the solution is to use licensed spectrum which effectively add to network costs. However, such sources of radio interference are unusual in rural areas.

2.5.2 Weather and Accidental Damage

Where there is severe weather, external antennas can be damaged. This may cause disruptions and increased costs due to replacement of antenna. However this is usually a rare incident.

2.5.3 Throughput

While wireless communication offers a better cost/performance ratio over time than leased data circuits, fiber optic connectivity offers an even better solution. This is however not the case in remote areas of the country side. The effects of the above limitations play an important role during the infrastructure deployment cost estimation process which is carried out in the planning phase. Where there is radio interference (although this is not the case in rural) cost change orders are to be expected to deal with interference at various levels. This also applies to antenna susceptibility to severe weather which can lead to other costly measures to secure them.

2.6 Different Wireless Technologies

Wireless networks are set to be the solution of providing low cost network infrastructure in remote and inaccessible areas. To understand better the cost structure of the wireless infrastructure, in the following section we discuss wireless technologies that can be deployed at varying costs in rural areas. We further show what makes those technologies dependable in rural environments.

2.6.1. Wireless Fidelity (WiFi)

WiFi (shown in Figure 2.5) is a wireless technology that serves as a last mile alternative to wire line network. It is common for LANs, but can also be used for wide area coverage. WiFi links with the end-user device that connects to the base station, the base station then connects to either wire line LAN or enterprise network infrastructure and then eventually to the Internet.

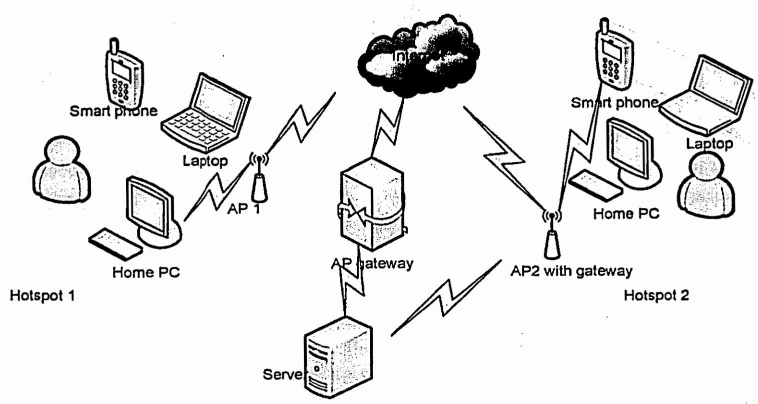


Figure 2.5: WiFi network. *(Adapted from Xirrus, 2005)*

The most encouraging trait of WiFi is that it operates in the 2.4 GHz band (ITAA, 2004) which makes it exempt from licensing since this is within the Industrial, Scientific medical band (ISM) which is license free. The impact of this is reduced capital expenditure (CAPEX) which is a desirable trend for developing network infrastructure in poor rural communities. The costs of acquiring a spectrum license represent a considerable fraction of the CAPEX (William, 2002) and obtaining a license in developing countries is nothing short of a mammoth task. WiFi is IEEE standard 802.11.a based, whose standardization has led to a healthy vendor ecosystem, and hence commoditizing equipment "has substantially lowered prices and simplified the installation and management of WiFi networks" (William, 2002).

Although there has been considerable wide spread of WiFi installation world wide, there has been less effort in developing cost models to support distributed service provisioning. William (2002) notes that the success of WiFi service model could help unlock the substantial investment in private networking infrastructure that could be used as the basis for constructing an alternative infrastructure to PSTN and cable wire line networks. The challenge with WiFi is that it cannot control interference from other WiFi service providers, which is critical especially when transporting delay sensitive services. Despite some drawbacks, the benefits of rolling out WiFi in rural parts of developing regions far much overweigh the interference problems. This is strengthened by lower interference in those areas as there is not much presence of interference sources. One of the salient benefits of

WiFi is that it reduces deployment costs. Even in areas with other network technologies "WiFi can seed a more complex array of potential business models that could fuel competition both at the retail level in service and at the wholesale level in alternative infrastructure" (William, 2002).

WiFi requires line of sight (LOS) and can cover a radius of few meters from the access point (AP), just about 100m. Since it operates at 2.4GHz, signal attenuation (RF Propagation Basics, 2004) is too high beyond few meters at this spectrum. To cover a large area with WiFi connection, more APs have to be installed creating a number of WiFi 'hot spots'. The CAPEX will also vary according to the number of APs to be installed. An increase in the number of APs would also increase the total deployment costs.

2.6.2 WiMAX

This section describes WiMAX particularly its characteristics that enable it to overcome obstructions from mountains and forests, and also its ability to deal with the transmission of large volumes of data over low frequency bands. Low power consumption for the CPE is another salient feature that is described; this is more desirable in rural areas where power is still problematic.

WiMAX and WiFi can work together to provide connectivity to a large geographical area. Figure 2.6 shows a typical WiMAX/WiFi network in rural areas.

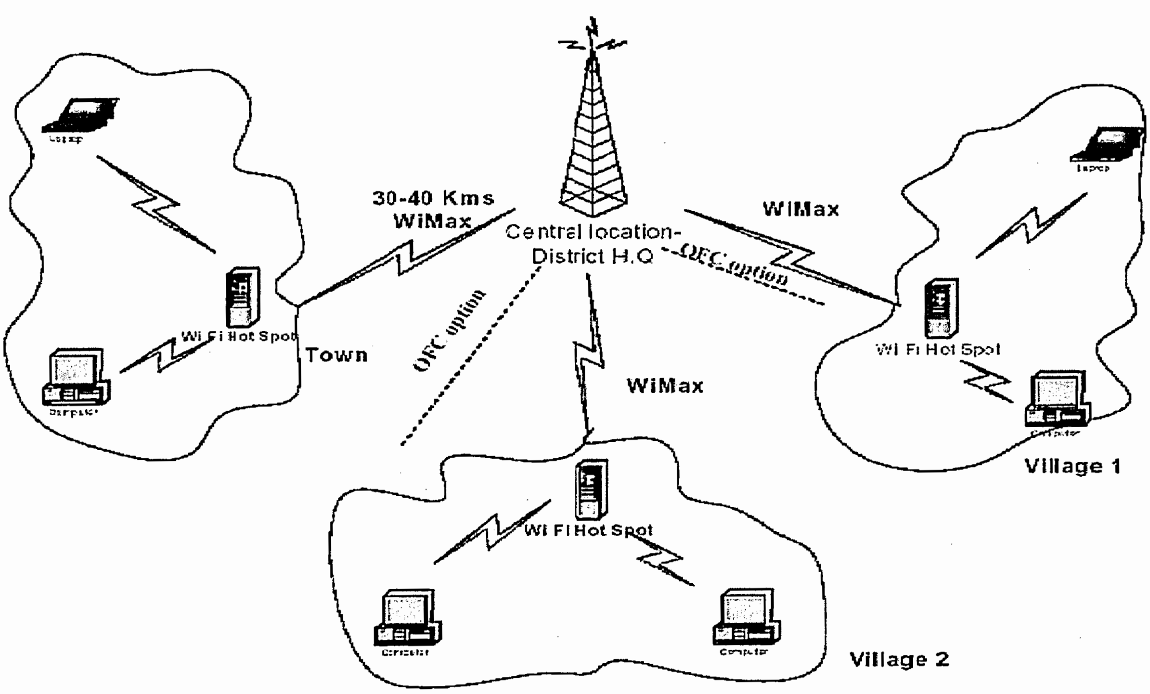


Figure 2.6: WiMAX/WiFi typical network (Joshi, 2006)

For both service providers and their customers the appeal of new technology depends on its ability to provide a better alternative, with 'better' often measured in terms of prices. The cost of WiMAX is critical because it has the potential to be both a complementary and a disruptive technology (Disruptive technology, 2007). WiMAX is an emerging wireless communications technology, popularly known as the IEEE 802.16 standard (Hung-Yu et al, 2005). It can provide Bandwidth Access (BWA) connectivity to a radius of up to 50km for fixed station and up to 15km for mobile stations. WiMAX operates on both licensed and unlicensed spectrums. The costs associated with licensing are eliminated when using the unlicensed spectrum. On the other hand, when using the licensed spectrum, interference is drastically reduced there by improving network capacity and scalability (Omerovic, 2006).

Market trends for WiMAX products in Africa where most of poor rural areas are; remain relatively low compared to developed countries. Figure 2.7 shows however that there has been a steady increase since 2006. The sharp increase in WiMAX products in the markets of developed continents is good news also for developing continents as this slowly brings down the costs of WiMAX products world wide. Compared to other continents the growth of WiMAX in Africa is still at a snail pace but the coming down of prices (*WiMAX Forum, 2004)* and possible development of infrastructure cost models is set to revitalize deployment of WiMAX across all rural regions.

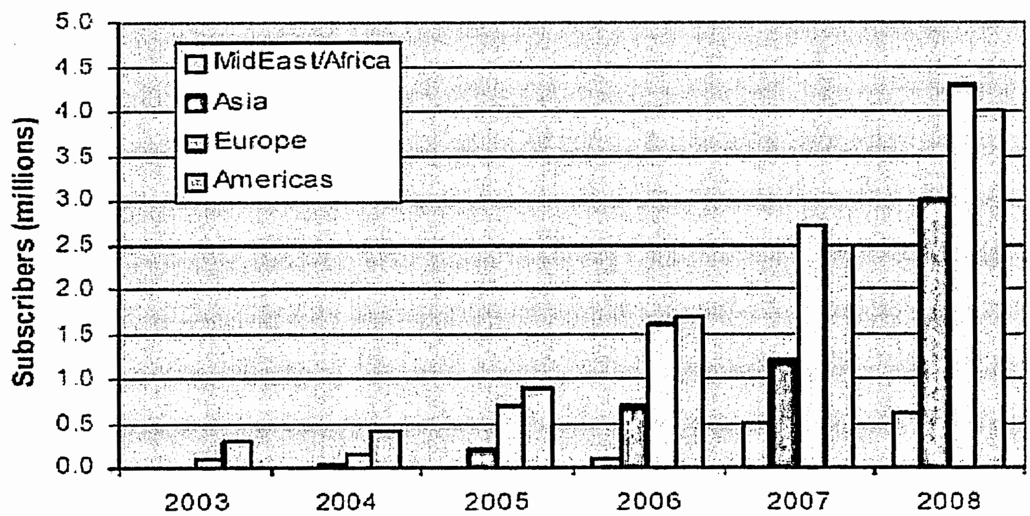


Figure 2.7: WiMAX Products World Market (WiMAX Forum, 2004)

WiMAX typically consists of a base station which includes indoor electronics and tower. A single base station can deliver service up to a radius of 10km. This range is usually extended, although theoretically (Omerovic, 2006) up to 50km radius. WiMAX also consists of the receiver which could be a stand alone box or a PC card that is endogenic in a laptop or computer. Transfer of data is better than WiFi, because WiMAX uses Orthogonal Frequency Division Multiplexing (OFDM) a technology that enhances the transfer of data (Omerovic, 2006). During data exchange authorization, WiMAX utilizes the grant mechanism. This is made possible by the Media Access Control (MAC) layer (Omerovic, 2006) which optimizes the utilization of radio resources. WiMAX has a number of better characteristics compared to WiFi. The following table 2.2 is a summary of these.

Table 2.2: WiMAX vs. WiFi (Omerovic, 2006)

	WiMAX	WiFi	Technical Differences
Range	Up to 30 miles-Typical cell size of 4-6 miles	Sub-300 feet(add access points for greater coverage	802.16 tolerate greater multi-path, delay spread.
coverage	Outdoor NLOS performance standard support for advanced antenna techniques.	Optimized for indoor performance, short range	802.16 systems have an overall higher system gain, delivering greater penetration through obstacles at longer distances.
Scalability	Designed to support hundreds of CPEs, with each CPE supporting many users	Intended for LAN applications, users scale from one to tens with one subscriber for each CPE devise.	802.16 can use all available frequencies, multiple channels support deployment, 802.11 is limited to license exempt spectrum.
Bit rate	Up to 75 Mbps	2.7bps/Hz peak up to 54 Mbps in 20 MHz channel	Higher modulations coupled with flexible error correction results in more efficient use of spectrum.
QoS	QoS built into MAC-voice/video service levels	No QoS support	802.11 is connection based MAC (CSMA/CA) basically wireless Ethernet. 802.16: Dynamic TDMA-based MAC with on demand bandwidth allocation.

Like WiFi, WiMAX standardization ensures reduced costs that could be incurred by vendors through development and verification of access control systems. Equipment costs are further lowered by successful manufacturing efficiencies (Omerovic, 2006) which have increased the production of components to exponential levels. Other benefits of WiMAX include "... lower backhaul deployment costs, rapid deployment and reconfigurability" (Omerovic, 2006). The WiMAX protocol is designed to work with several data transmission techniques e.g. VoIP, which makes it suitable to provide integrated services (Raju, 1999). WiMAX is prolific in terms of the utilization of radio resources. It utilizes the grant request mechanism (GRM) through the media access control (MAC) layer leading to optimized radio resource utilization. A salient feature of WiMAX is its ability to provide service on line of sight (LOS) as well as on non-line of sight (NLOS).

2.7 Suitability of WiMAX for Rural Environments

In this section we discuss various WiMAX technologies that make its deployment suitable for rural areas hence a good option if one is developing a cost model for communication networks in those environments.

2.7.1 LOS and NLOS Environments

The radio channel of a wireless communication system is described as LOS or NLOS (WiMAX Forum, 2004). Many fixed wireless broadband provide line of sight coverage. In LOS there is 'straight' unobstructed path through which the signal will travel from the transmitter to the receiver. The absence of obstruction guarantees more signal strength and improve coverage. Link determination in LOS is guided by the Fresnel clearance zone as shown in Figure 2.8.

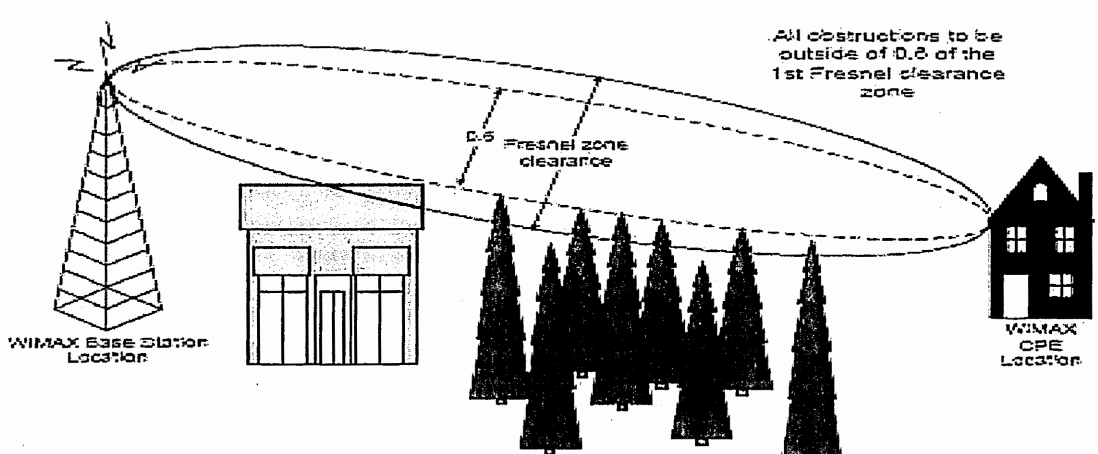


Figure 2.8: LOS Fresnel Zone (WiMAX Forum, 2003).

In other words to avoid a reduction in signal strength, LOS link should be free from obstruction in most of the first Fresnel zone (WiMAX Forum, 2003). The Fresnel clearance depends on frequency and distance between transmitter and receiver locations (WiMAX Forum, 2003). It is at times necessary to increase the height of the antenna to the level which is clear from the Fresnel zone. This however affects cost estimation process by increasing antenna cost as their cost is proportional to their height.

With NLOS the situation is totally different. Signals travel on a path with a lot of obstructions. The signal bounces against objects of obstruction (see Figure 2.9) and reaches the receiver through reflections, diffractions and scattering (WiMAX Forum, 2003). Coverage is very important for connectivity hence a number of impediments can limit the potential coverage. There are challenges notwithstanding, which include overcoming building penetration loses; covering reasonable distances with lower transmit powers. NLOS reduces installation costs on CPE installation as well as antenna height since there is no need to raise it to the level of Fresnel zone of clearance. This is further strengthened by WiMAX's features that make it possible to use indoor customer premise equipment (WiMAX Forum, 2003).

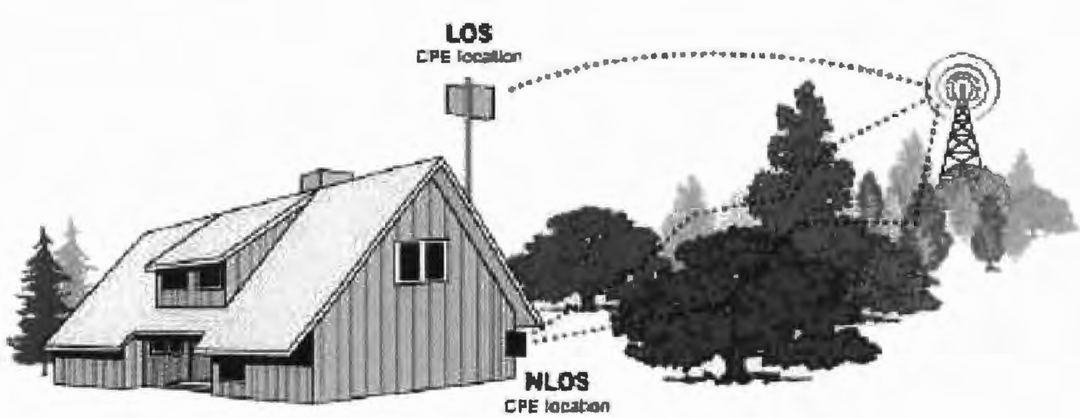


*Figure 2.9: NLOS CPE Location (*WiMAX Forum, 2003).

2.7.2 NLOS Technologies

Problems associated with NLOS require rigorous technologies to solve them. Such problems range from selective fading, delay spread to link budget. Hence several technologies have been developed to deal with these problems. In this section we discuss three common ones; the orthogonal frequency division multiplexing technology, the sub channelization transmit and receive diversity and the adaptive modulation.

2.7.3 The OFDM Technology

The OFDM is a technology that transmits multiple signals simultaneously over the transmission path. The WiMAX OFDM waveform offers the advantage of being able to operate with larger delay spread of the NLOS environments (WiMAX Forum, 2003). The driving force behind OFDM is the desire for faster wireless technologies and the increase in multimedia applications. One of the benefits of OFDM is resiliency to RF interference and to lessen signal distortions. The OFDM's importance in enhancing WiMAX's low CAPEX is revealed in its advantages cited by Luna (2007). According to the author (Luna, 2007), the immunity to delay spread and multipart, the resistance to frequency selective fading, simple equalization and efficient bandwidth are desirable advantages the OFDM gives to WiMAX. Carrier equalization is very important for signal strength. It is easier to equalize the individual OFDM carriers than to equalize the broader single carrier signal (WiMAX Forum, 2003). Figure 2.10 illustrates this assertion.

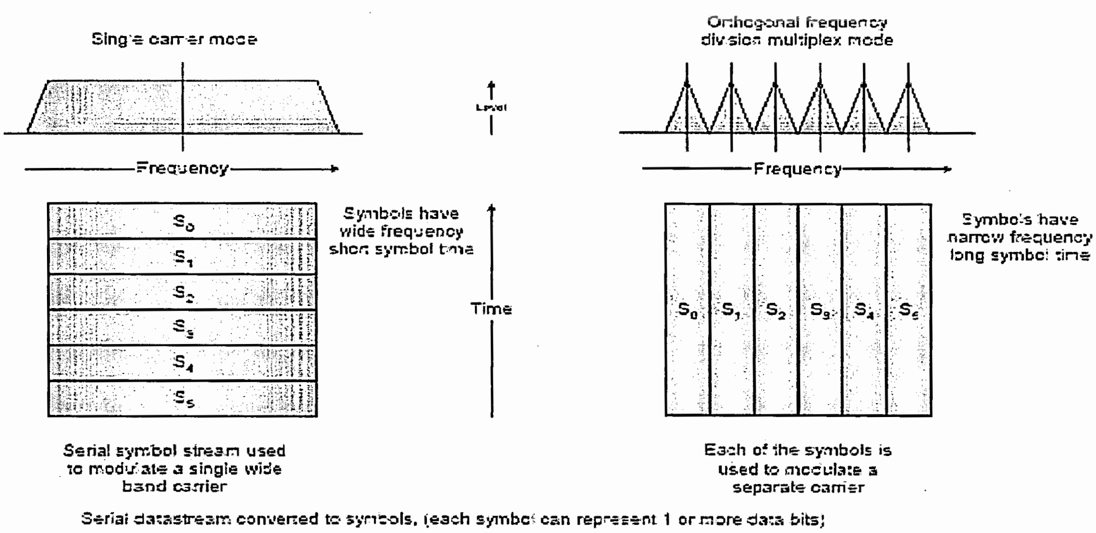


Figure 2.10: Single Carrier and OFDM (WiMAX Forum, 2003)

As shown in Figure 2.11 the single carrier mode achieves less receiver input than the OFDM. The basic idea of OFDM (WiMAX Forum, 2003) transmission is to divide the available bandwidth into a number of subcarriers. If the number of subcarriers is large enough, the bandwidth per subcarrier is narrow compared to the coherence bandwidth

(WiMAX Forum, 2003) of the channel. Therefore, each subcarrier experiences approximately flat fading.

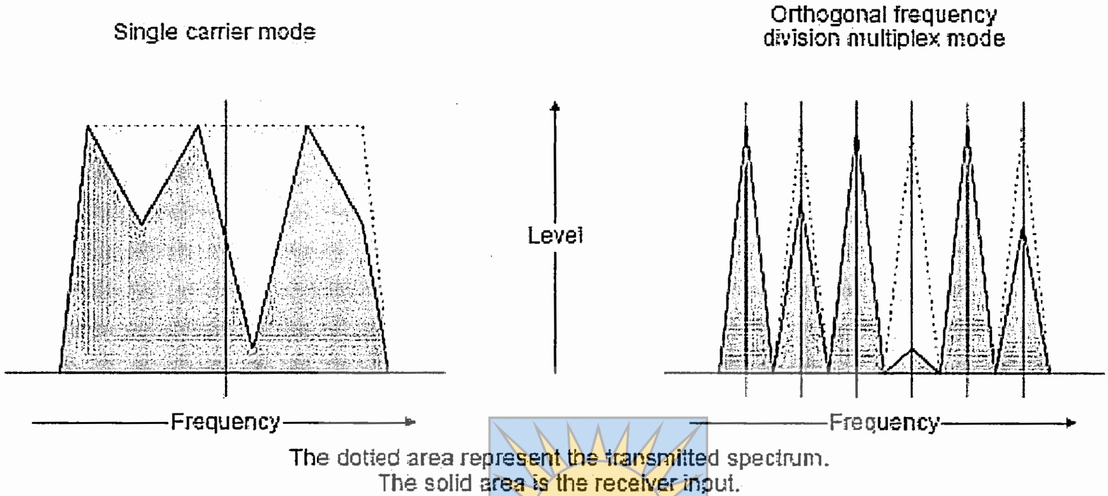


Figure 2.11: Single and OFDM received Signals (WiMAX Forum, 2003).

2.7.4 Sub Channelization

Sub channelization allows OFDM and other sOFDMA to split channels up into sub channels. Sub channelization makes the transmit power to be concentrated on fewer OFDM carriers, and by so doing it increases the system gain that can either be used to extend the reach of the system, to overcome the building penetration loses, and or to reduce the power consumption of the CPE (WiMAX Forum, 2003). By using frequency utilization concept, WiMAX realizes the transmission of large volumes of data in limited frequency bands. Sub channelization considerably achieves an increase in the number of frequency channels. A user in close proximity to the base station would normally be assigned to a larger number of channels with a high modulation scheme such as; the 64 quadrate amplitude modulation (QAM) (WiMAX Forum, 2003) to deliver the most data throughput to that user. Sub channelization is discussed extensively in (Kaitz, 2000).

2.7.5 Transmit and Receive Diversity

In wireless communication channelling signals encounters signal fluctuations and fading. Diversity is the technique to control fading in wireless links. There are two instances of diversity, the transmit diversity and the receive diversity. The transmit diversity is applicable when multiple antennas are used at the transmitter. The receive diversity improves capacity and range capability at the base station and it is a very efficient technique to mitigate fading within a signal.

2.7.6 Adaptive Modulation

When there is signal fade (Capsuto and Frolik, 2006) WiMAX adjust to maintain connection through a dynamic shift to lower modulation. Adaptive modulation allows the WiMAX system to adjust the signal to noise ratio (SNR) condition of the radio link (Capsuto and Frolik, 2006).

2.8 Determinants of Wireless Network Selection for Rural Environments

According to Lopez et al (2004) the right selection of the wireless solution is determined by a wide range of factors which include technological capacity, range, noise immunity, noise emission, security, setup and running costs, power consumption, free versus licensed operation, regulations, compatibility with hazardous environment, fault tolerance, technological availability, commercial availability and quality of service (QoS). In this section we discuss capacity, range, setup and running costs, free versus licensed operation and technological availability which we consider important in a rural environment. However, works on noise immunity can be found in Xu et al (2003) and noise emission is discussed in Quinlan (1999). There are also vast sources which deal with security issues including Karygiannis and Owens (2002). Issues on the compatibility with hazardous environment are dealt with in Lopez et al (2004). The fault tolerance is discussed in Xiang et al (2003), while issues on commercial availability are mentioned in Tarwireyi et al (2007). Profound research and publications have been done on the QoS of wireless technologies. Lorenz (2002) gives more details in that regard.

2.8.1 Network Capacity

The network's capacity is the maximum amount of data or number of users that can be simultaneously on the network. Network capacity depends on network size, traffic pattern and local radio transitions. Each access point (AP) has maximum bandwidth and the total bandwidth divides across the total number of users currently using that AP. When deploying wireless infrastructure, there is need to consider the number of people to be serviced, the locations as well as applications to be used as these will determine the minimum bandwidth required. This also determines cost estimation of deployment as costs increase with the increase of available bandwidth.

2.8.2 Network Range

The range of a network is the area around the AP within which a client can connect to the network. To improve range, the wireless router is to be positioned central to the area. When operating at limits of range, the performance may drop, as the quality of connection deteriorates with distance from the AP. Range is very important when selecting wireless technology to be used, as extending connectivity to the whole desired area involve costs. For instance to improve quality of network connection more APs may be needed, and this increases costs of network deployment.

2.8.3 Setup Costs

The setup costs are costs in putting up network infrastructure and finally putting it to operation. For economies of scale, those costs should not be too high. The trend is that the technology with lower set up and running costs will be preferred or the other factors will come in also such as the area to be connected and type of services to be offered by the network.

2.8.4 Free versus Licensed Operation

There are usually barriers in spectrum licensing which include bureaucratic procedures through the regulating body. The control of spectrum is very fundamental for a number of reasons: to ensure QoS of the network and to avoid interference. However, since spectrum licensing increases the Capital Expenditure (CAPEX), the use of unlicensed spectrum will tremendously reduce the CAPEX. The use of unlicensed spectrum is ideal for short range wireless technologies to avoid massive interference. The ideal location to use unlicensed spectrum will be in the rural areas of most developing countries as there is less likelihood of strong interference.

2.8.5 Technological Availability

The technology to be preferred for deployment must be available local and costs should be reasonable. Most of the wireless technologies are now available in most developing nations and the proliferation of numerous vendors because of standardization, have helped in driving the costs of equipment down (Geri, 2003). Most WiMAX and WiFi technologies are now available at reasonable prices in most developing nations. Further more wireless network cost models can now be built using them.

2.9 The Cost structure of Communication Networks

The total cost of deploying communication networks is a summation of Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) as represented in Figure 2.12. CAPEX include costs associated with site preparation, installation, labour and equipment. When the network has been set up, recurrent costs which make up OPEX originate from site lease, maintenance, power backup and backhaul. All the cost process is affected by cost change orders whose occurrence may be random and tend to cause the fluctuation of the network costs. The issue of cost change orders is discussed in later chapters of this thesis since it is important to our network cost model.

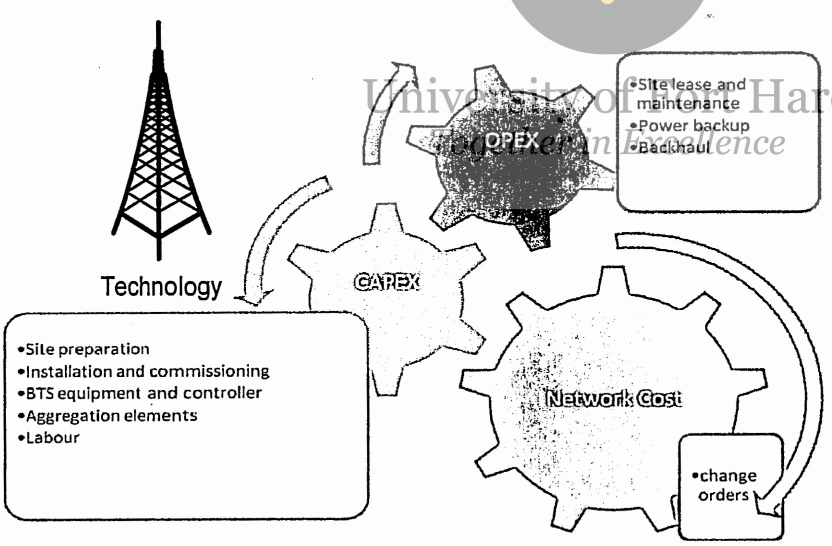


Figure 2.12: Cost structure of communication networks

2.10 Feasibility of Wireless Technologies for Rural connectivity

An important fact in the search of technologies for a rural cost model is the realization of the trade-offs between coverage and capacity. In fact, the most feasible wireless solution is a combination of technologies to enable increased mobility and scalability. In Figure 2.13 WiMAX is shown providing coverage to a larger area that encompasses a number of villages far apart. There are public places that may fall within this area, e.g. schools, small business compounds etc. These may use WiFi within their localities to increase capacity and improve cost effectiveness. NLOS connectivity provided by WiMAX enables linking of villages even across rough terrain.

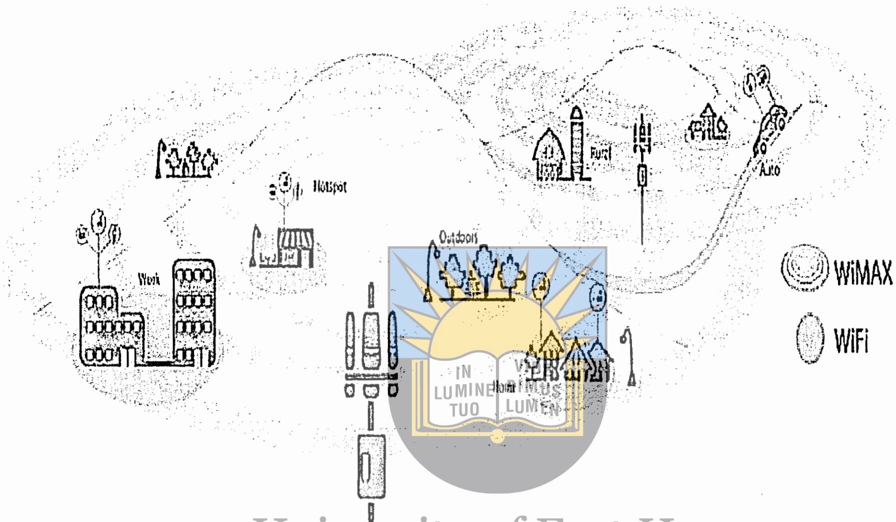


Figure 2.13: Wifi-WiMAX synergy (Motorola and Intel, 2007)

2.11 Conclusions

Wireless networks are a viable option for any rural network cost model. In this chapter we have presented different standards of wireless technology deployments and described their suitability to rural areas. The standards include the IEEE 802.11 and the IEEE 802.16 popularly known as WiFi and WiMAX respectively. Wireless networks transmit signals through electromagnetic spectrum. Transmission technologies of wireless networks include radio systems and microwave systems. The radio system carries out transmission using radio waves which act as a carrier of information. The basic components required for operating microwave links are the transmitters, towers, antennas and receivers. Variation in tower length has a strong effect on the estimation of infrastructure costs, as the size of the tower is related to its costs.

The propagation of signals can be done not only on a LOS path, but also through sky wave from signal components reflected off the troposphere and a path diffracted from an obstacle in the terrain. This chapter has also outlined the issue of signal fade as the distance to the receiving antenna increases. This can be reduced through the establishment of more antenna sites at shorter distances, which have a bearing in increasing network infrastructure costs. Considering the cost structure of wireless networks, we have discussed determinants that are a key in modelling infrastructure costs. These include; network capacity which is the maximum amount of data that can be handled by the network, the network range which is the area around the AP, free or licensed spectrum and the availability of the technology. In addition to the determinants of network infrastructure costs the cost estimation techniques play a pivotal role in building cost models. In the following chapter we discuss various cost modelling constructs and different cost estimation techniques.

CHAPTER THREE

GENERIC COST MODELLING FRAMEWORK AND RELATED WORK

3.0 Introduction

In today's dynamic technological landscape cost model frameworks have become an important part of development. A cost model framework is a theoretical construct that represents economic processes by a set of variables and a set of logical and quantitative relationships between them (Economics, 2005). The most outstanding point is that a model describes the original object without having to deal with all its characteristics and complexities. A model has a number of uses, but one which caches our interest is that of forecasting economic activity in a way in which conclusions are logically related to assumptions (Economics, 2005). Most models today have either a scientific or business orientation. To be precise, cost models are business models.

There has been a plethora of research works related to cost modelling some of which have helped to transform the economic landscape of communication infrastructure deployment. In this chapter we make a review of the cost models and discuss their various constituencies and dependences among those constituencies. The cost estimation process is vital to support decision making for communication network infrastructure deployment hence we discuss various issues of cost estimation. These include demands for cost models, skills that are needed for cost estimation, steps of cost estimation, credible cost estimation and what is involved in developing credible cost estimates. There are a number of cost estimating techniques that are used to build cost models; most of them can be grouped under algorithmic or non algorithmic. Both categories are discussed in this chapter. The non-algorithmic estimation methods that we discuss in this chapter include; Expert judgement, Estimation by Analogy, Fuzzy Analogy and Artificial Neural Networks. The algorithmic methods discussed are; Mean Least Square Regression, Parametric methods, Method of Scales, Engineering estimation and Capacity Factored Estimation. The two terms; techniques and methods are used interchangeable in this chapter. The chapter also discusses some related works by various authors as we drew a number of inspirations from those scattered works. Finally we end the chapter by giving a summary of our discussions.

3.1 Overview of Cost Models

The concept of cost models has been the centre of research in financial analysis and considered important in various economic disciplines. This has resulted in a number of definitions that try to define a cost model. Although it is difficult to nominate any of those definitions and say this particular one is the most befitting, we consider the following as central in our work; that a cost model is a set of mathematical relationships arranged in a systematic sequence to formulate a cost methodology in which outputs, namely cost estimates, are derived from inputs (DOE, 1997). The most distinguishing attributes here are the outputs and inputs. Interest is vested upon ascertaining the effects of inputs in shaping or controlling the outputs. In other words cost models are designed to effect measures to control cost overruns (Deccan, 1997).

In order to model costs its various constituencies have to be considered. As cited in (Deccan, 1997) the constituencies of any cost model are; infrastructure definition, tasks, design model, task models and cost elements, which are shown in Figure 3.1. The figure shows the data levels of cost models with three tiers. The first tier is the infrastructure definition; the second tier consists of the tasks and the design model while the third tier consists of the task models and the cost elements. The cost elements are developed from task models. The development of tasks lead to the design of the model and these are in the same tier.

In the case of a network deployment model the infrastructure definition is the technology selection. That is, the preferred technology when considering a number of factors which include feasibility, availability and cost, as well as affordability of the technology. These factors also determine the selection of other components like antenna type. Tasks are activities associated with deploying say the infrastructure, i.e. site survey, feasibility study and requirements analysis. The design model as a component constitutes model variables and cost element factors which are defined for each task. Resources to be used in each task are also ascertained. The task models (Figure 3.1) show task variables and their associations with a number of relevant equations. For instance if we consider labour as a task, it can be determined by equations associating hours and rate per hour (Deccan, 1997). There are interdependencies among the cost elements of all the model's constituencies necessitating high level of cost management. In the following section we look at the cost modelling cycle.

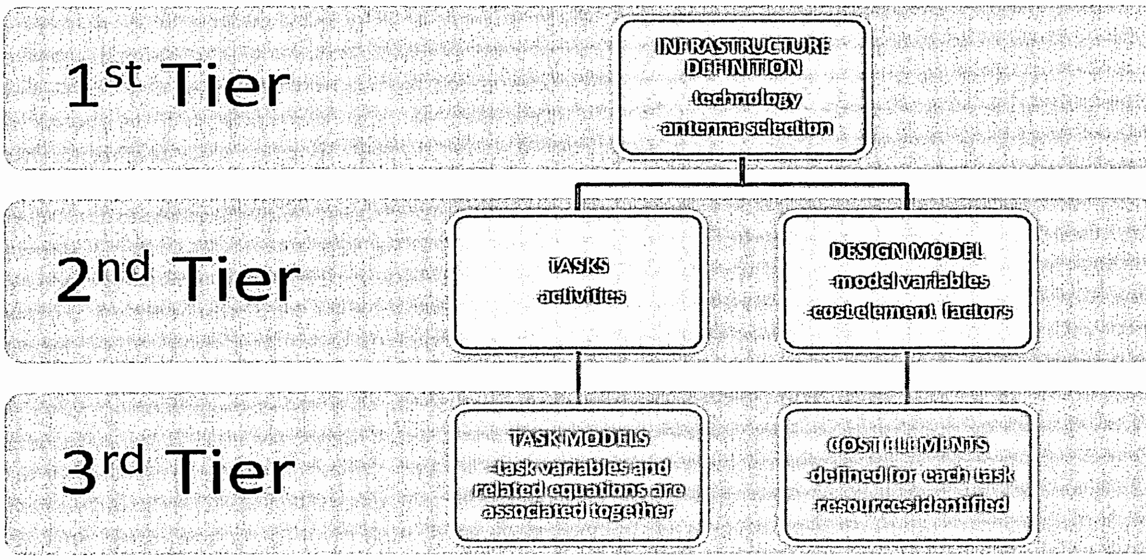


Figure 3.1: Data Levels of Cost Models (Deccan, 1997)

3.1.1. Cost Modelling Cycle

Every cost model is designed to minimize the estimated CAPEX and OPEX (Wolfgang, 2008) while at the same time optimizing revenues. This is somehow an iterative complex process that is better understood through the cost modelling cycle illustrated in Figure 3.2. In this cycle the technical concept refers to options and selection of technology for deployment. In network deployment the determinant is the rate of gap reduction between projected costs and projected revenues. A higher rate of the gap reduction indicates that the deployment costs are quickly recovered and the returns quickly become positive. Therefore the cost model can be said to be optimal. On the other hand a lower rate of gap reduction would indicate that positive returns would take long to be realized hence the model needs further calibration and sensitivity analysis. Various technologies are to be economically assessed (Wolfgang, 2008) and all technicalities associated with them considered. The rollout plan specifies a range of services that will kick start the operation of the network. Again this is arrived at after considering a number of factors that include possible adoption, diffusion (marketing factors) and disposable income for the potential adopters.

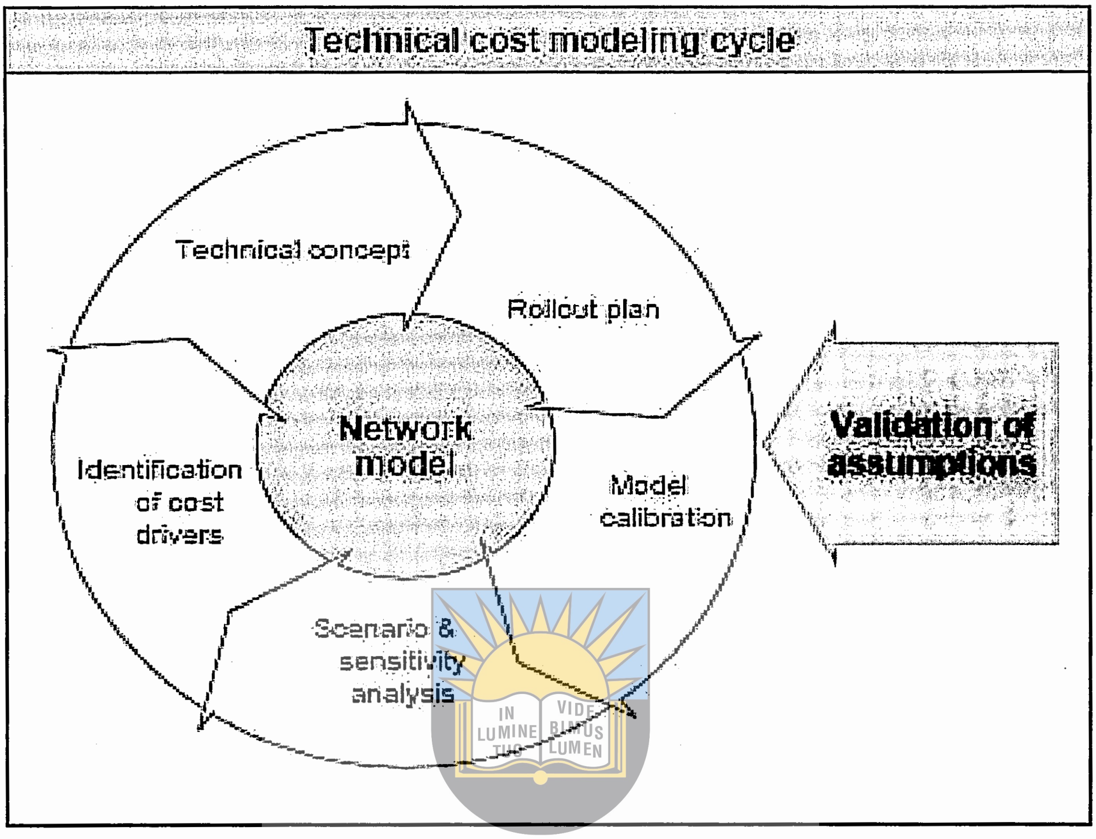


Figure 3.2: Technical Cost Modelling Cycle (Wolfgang, 2008)

Model calibration is necessary to validate (Wolfgang, 2008) the significance of model results. Calibration is a way of standardizing the model. When models are developed they are developed for specific situations. Outside such situations they become irrelevant and of little direct use. Related models therefore play an integral part by influencing the cost modelling methodology through pre-calibrated parameters. Calibration allows the determination of any deviation from a standard related model so that the correction factor can be computed. When calibrating the model is run with normal inputs against items for which the actual costs are known. The obtained estimates are then compared with the actual costs and the average deviation becomes the correction factor for the model. It is the data used that determines what type of calibration is done. In essence, the calibration factor obtained is really good only for the type of inputs that were used in the calibration runs. Sensitive analysis presents an opportunity to experiment with parameter changes. Sometimes it is necessary to do sensitive analysis with different assumptions or model bounds for example using a different technology, this is defined by the scenario analysis phase. The results that are generated during experimentation have an indispensable role in the model cycle. They enable identification of the cost drivers. These can then be successively minimized to influence the rollout plan and total deployment costs. Furthermore the identification of cost drivers is directed by the different cost categories of cost models.

3.1.2 Cost Categories in Cost Models

There are two types of costs that are common with cost models; the economic costs and the accounting costs (Confraria, 2001). In Figure 3.3 these two types of costs are shown with their extended synthesis.

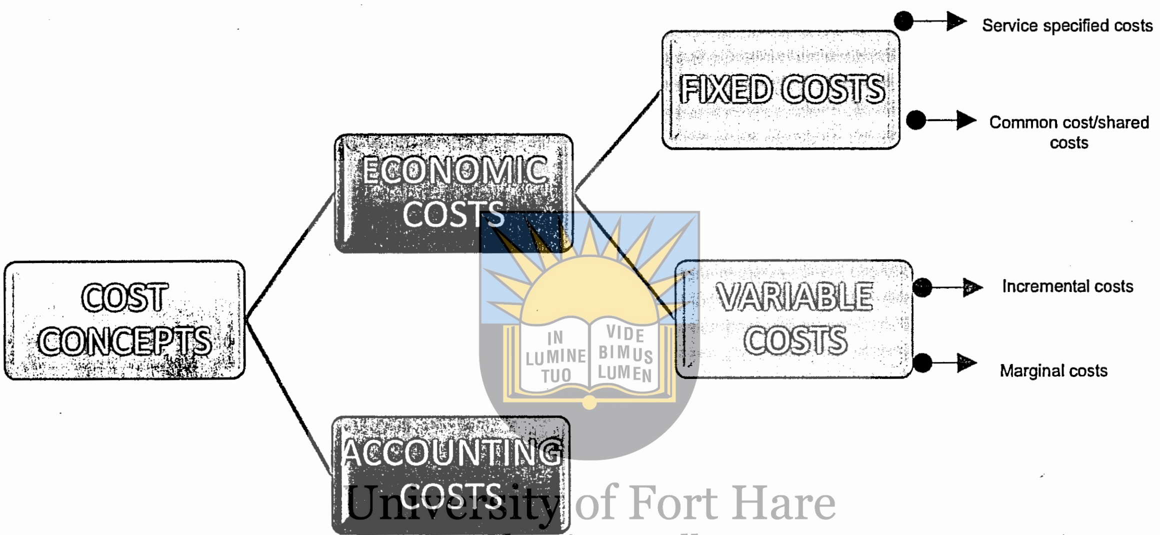


Figure 3.3: Cost Categories (Confraria, 2001)

The economic costs are costs that arise as a result of adding a new service (Confraria, 2001) or an alternative. This however can also include providing the service for the first time where previously there was no similar service. Economic costs further split into fixed and variable costs. The costs that are fixed consists of service specific costs which are a result of providing specific service whose costs are eliminated if the service is not included for deployment. Another composition in fixed costs is shared costs incurred through the provision of a group of services. Common costs are shared by all services. Variable costs tend to vary in direct proportion to the increase of parameters in a cost model. The costs of each parameter may vary as a result of time space for example in a network infrastructure cost model labour costs may change from time to time and from one geographical place to another. One of the outstanding attributes of variable costs is that they frequently factor into profit projections and the calculation of break-even points for a cost model. The contribution of this is the gain in terms of "insights into the cause-and-effect relationships" (DOE, 1997: 3) that exist in that particular model.

Accounting costs are historical in nature. They are collected from previous records of the organization or company. Such costs can represent the expenditure on purchasing various equipments for network deployment for example. This reflects capital costs of equipment and other related costs incurred in carrying out tasks for the project. There are problems that are associated with this kind of approach (Confraria, 2001); firstly not every detail is likely to be recorded in books so estimating costs based on historical data only can lead to inefficiencies in the allocation of resources. Secondly, the fact that the whole exercise depends on the information provided by the company means that any error in the information provided will lead to inherently wrong estimates.

3.1.3 The Cost Model Management Process

In deploying network infrastructure the cost is one of the corner stone foundations supporting the deployment's success or failure, the other two are the deployment schedule and the network performance. All projects that go beyond their perceived budget are either abandoned or put on hold while other funds are being sorted. One of the reasons that lead many projects to failure is lack of proper project cost management. The root cause is that more often than not, cost estimates are rushed and not given time to gather all the historical data, there is also inability to select appropriate estimating methods and select the proper technology. When estimates are rushed the danger is that at a later stage the tendency is to consider them as actual costs and ignore some risk planning measures that should accompany cost estimates. Figure 3.4 illustrates the project management process.

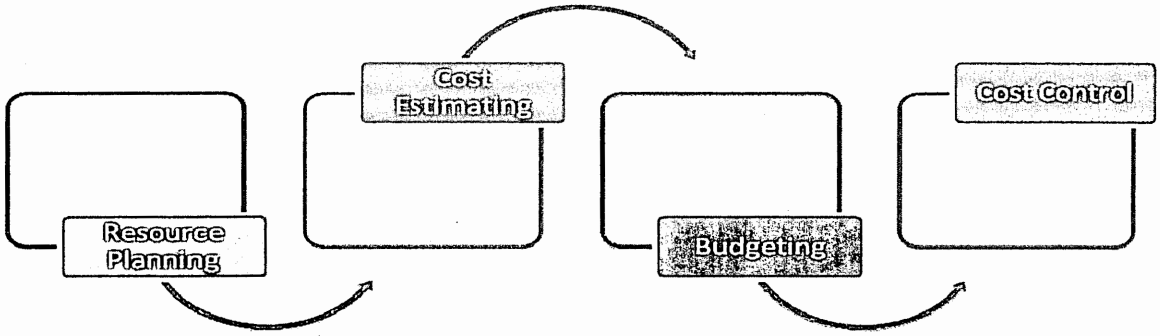


Figure 3.4: Project cost management process

Among the four processes for the purposes of this work we make a discussion on cost estimation. However detailed information on resource planning, budgeting and cost control can be found in various literatures that includes (Chapman, 1997; Flemming, 1998).

3.2 Cost Estimation

There are several strategies used to determine the costs of a project. In most communication network projects the total costs pertains to CAPEX and OPEX. Therefore being able to identify CAPEX cost drivers and OPEX cost drivers can lead to better project cost estimates. However we are quick to say identifying cost drivers only will not produce accurate estimates, in addition there has to be a careful selection of cost estimating elements (Guide, 2000). In Figure 3.5 we illustrate some of cost estimating elements.

Inputs are used by the estimating process to calculate estimates for each activity and also help determine the right techniques that could give accurate estimates. The actual calculation is done by the tools. The tools shown in Figure 3.5 are discussed in the later sections. Products as elements of cost estimation include cost management plan the cost estimates that are produced by the tools as well as supporting details to justify the estimates.

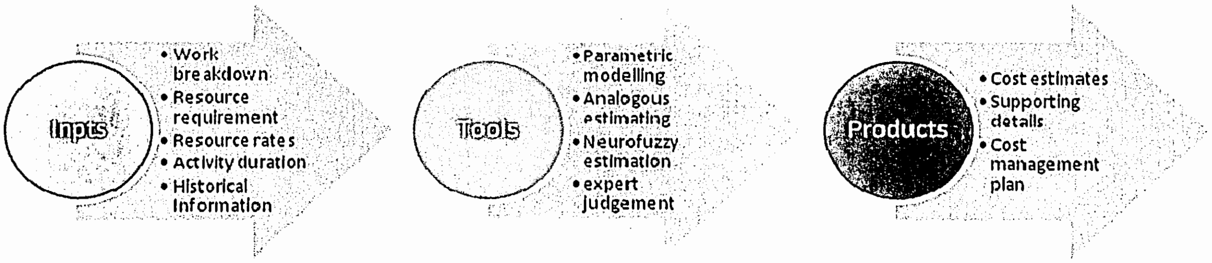


Figure 3.5: Cost estimating elements (Guide, 2000).

3.2.1. Demands for Estimation Models

Estimation as the process of producing an approximation for cost in different stages of communication network deployment is necessary for identifying and considering cost alternatives. At the initial stage the project needs to be justified through a comparison between different technologies and to anticipate benefits. The project needs to be understood before its inception and to secure required resources. Further more, the dire need to control costs during network deployment has necessitated focus to be on estimation models which allow simulation of the deployment process. Simulating estimation models is the basis of influencing the factors that create changes to the cost baseline. Competitive advantage among network deployment companies has also been behind a rising demand for estimation models, not only leading to their proliferation but also to their enhancements for monitoring cost performances to detect variances. Estimates are also central to decision making and are used to establish the metrics against which the successes of project deployment will be measured.

3.2.2. Skills Needed for Cost Estimation

The cost estimating process is very demanding in terms of skills. It requires sound skills for the process to be completed. Various specialists' knowledge is represented during the whole process of estimation as shown in figure 3.6.

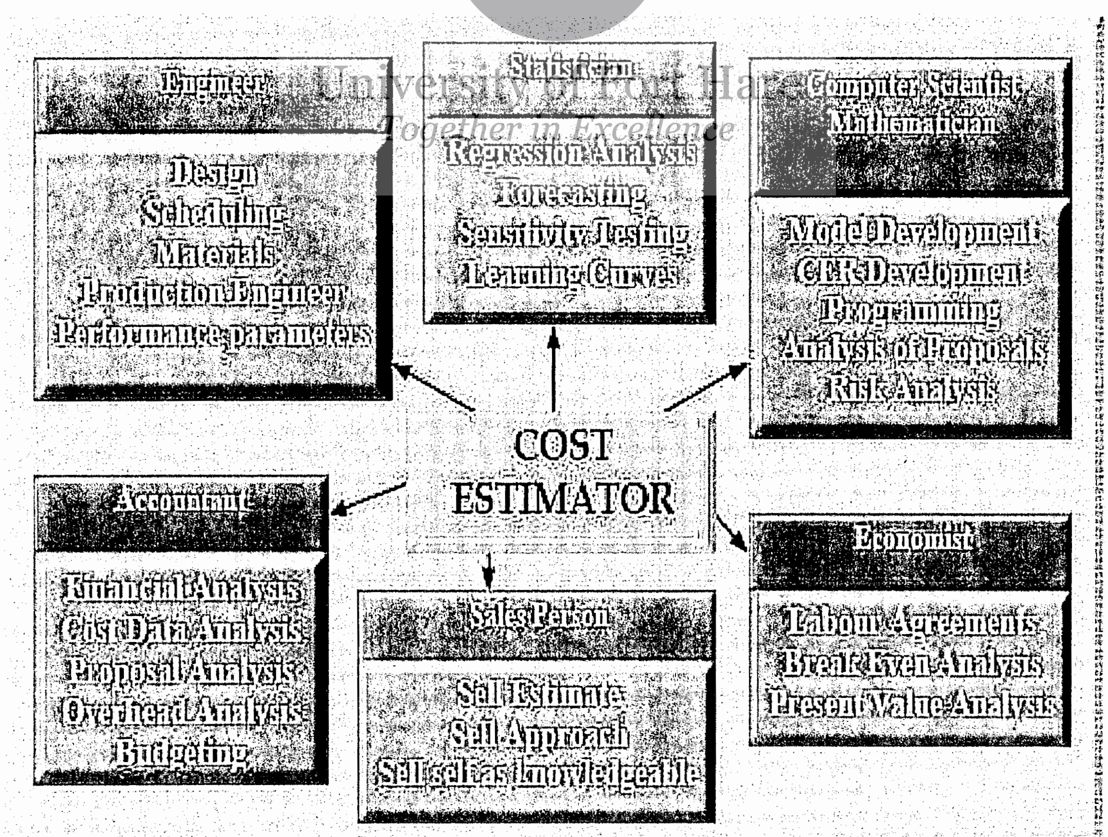


Figure 3.6: Skills and knowledge of cost estimating (Hammaker, 2000)

The cost estimator should have integral skills to design the cost model and draw performance parameters. Statistical knowledge is required for sensitivity testing and to interpret the learning curves. Developing a cost model need a lot of data collection and this cost data ought to be analysed, this calls for accounting skills. In overall the cost estimating process integrates the skills of an Engineer, a Statistician, Computer scientist, a Mathematician, an Economist, a Sales person and an Accountant as illustrated in Figure 3.6.

3.2.3. Developing Credible Cost Estimates

To achieve credible cost estimation is really a long and sometimes a complex process. The estimation process involves a number of activities which can be summarised in 10 steps (GOA, 2007) as shown in Figure 3.7.

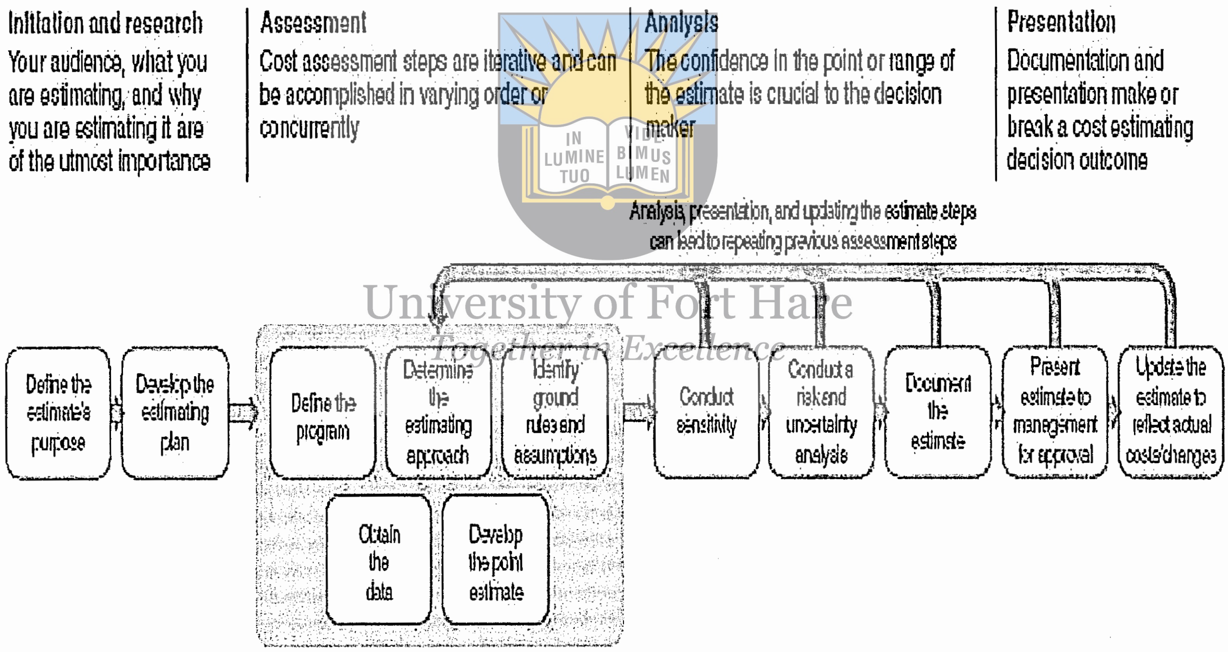


Figure 3.7: Cost estimating process (GOA, 2007)

3.2.3.1. Steps of Cost Estimating Process (GOA, 2007):

3.2.3.1.1. Define Estimate's Purpose

Cost estimates have various purposes and these are determined by the estimates' intended uses (GOA, 2007). To begin with, the intended use of the estimates must be very clear and its scope is also dependent on the needs of the users. Availability of data is critical at this stage, should there be lack of it estimation is bound to produce inaccurate results. Another important aspect in the definition phase is that of schedule. No matter how detailed the data may be for the model, time constraints can still have a negative impact on the cost estimates. That is if the work breakdown structure (WBS) over-saturates the time schedule, then the quality of the estimate can be compromised. Too congested time schedule leads to unnecessary rush as the working team will try to complete all tasks within that time schedule.

3.2.3.1.2. Develop Estimating Plan

The cost estimation procedure needs to be well outlined. This includes formulating relevant equations appropriate for particular tasks. During this step a realistic timeline is developed that will fit well the WBS into the time schedule.

3.2.3.1.3. Define the Program Characteristic

Clarity is required on the acquisition strategy, technical definition, characteristics, system design features and technologies to be included in its design (GOA, 2007). Defining the program also includes provision of information on development, testing procedure and installation (GOA, 2007).

3.2.3.1.4 Determine the Estimating Approach

Defining the WBS and identifying every element in the program is central to this step. The purpose of the WBS is to indicate the time frame and what needs to be done at any particular timeline. It also shows how activities relate to one another.

3.2.3.1.5 Identify Ground Rules and Assumptions

As we have mentioned before not all data needed may be available. Therefore the cost estimation also depends on a number of constraints which include assumptions. Reference is being made to rules that form the basis of conditions under which the cost estimate is treated as reliable. Ground rules form "a common set of agreed on estimating standards" (Shepperd and Scholfield, 1997) whose purpose is to minimize conflicts and give some guidance. However, in the absence of ground rules then assumptions must be made for the cost estimation to proceed.

3.2.3.1.6 Conduct Sensitivity Analysis

During this step inputs are varied to see their impacts on the output estimates. Furthermore this exercise validates assumptions made and provides direction if some assumptions need to be modified.

3.2.3.1.7 Risk and Uncertainty Analysis

Drawing a number of assumptions would make cost estimation to proceed even if there is insufficient data. However this does not come without a price, assumptions tend to introduce uncertainties. To deal with this situation acceptable statistical analysis methodology must be employed. The confidence level is also determined during this step. In addition cost risks are outlined and risk planning is implemented.

3.2.3.1.8 Document the Estimate

This step emphasises on documenting the steps used in the cost estimation process. All ground rules and assumptions, parameters, methods and calculations are included in the resultant document.

3.2.3.1.9 Present Estimates

After all documentation has been done a logical briefing is in order to get people's views and experts' opinions which may be used as recommendations. Estimates can be presented in various forums that include public lectures or even conferences.

3.2.3.1.10 Update the Costs to Reflect Actual Costs and Changes

The idea here is that the cost estimates should revolve with time in order to adapt to cost changes that might occur. In other words, cost estimates need to be revised from time to time so as to keep them current.

3.2.4 Credible Cost Estimation

While estimating models are a necessity, they should always enshrine integrity, risk and uncertainty handling mechanisms. Estimates must be precise or near precise to maintain operators' confidence and trust (such estimates are referred to as credible cost estimates in (GOA, 2007). At the same time project risks must be identified in the estimation to mitigate them and cater for uncertainties. To have cost estimates that enshrine the above mentioned they must satisfy all characteristics of credible cost estimates (GOA, 2007); Table 3.1 shows the characteristics of effective cost estimating.

Table 3.1: Basic Characteristics of Credible Cost Estimates (GOA, 2007)

Characteristic	Description
Clear identification of task	Estimator must be provided with the system description, ground rules and assumptions, and technical and performance characteristics. The estimate's constraints and conditions must be clearly identified to ensure the preparation of a well-documented estimate.
Broad participation in preparing estimates	All players should be involved in deciding mission need and requirements and in defining parameters and other system characteristics. Data should be independently verified for accuracy, completeness, and reliability.
Availability of valid data	Numerous sources of suitable, relevant, and available data should be used. Relevant, historical data should be used from similar systems to project costs of new systems. The historical data should be directly related to the system's performance characteristics.
Standardized structure for the estimate	A standard work breakdown structure (WBS), as detailed as possible, should be used, refining it as the cost estimate matures and the system becomes more defined. A Major Automated Information System (MAIS) program may have only a cost estimate structure. The WBS ensures that no portions of the estimate are omitted and makes it easier to make comparisons to similar systems and programs.
Provision for program uncertainties	Uncertainties should be identified and allowance developed to cover the cost effect. Known costs should be included and unknown costs should be allowed for.
Recognition of inflation	The estimator should ensure that economic changes, such as inflation, are properly and realistically reflected in the life-cycle cost estimate.
Recognition of excluded costs	All costs associated with a system should be included; if any cost has been excluded, it should be disclosed and given a rationale.
Independent review of estimates	Conducting an independent review of an estimate is crucial to establishing confidence in the estimate. The independent reviewer should verify, modify, and correct an estimate to ensure realism, completeness, and consistency.
Revision of estimates for significant program changes	Estimates should be updated to reflect changes in a system's design requirements. Large changes that affect costs can significantly influence program decisions.

3.2.5 *Cost Estimating Techniques*

There are a number of cost estimating techniques that can be used in cost models. In general there have been three main categories of cost modelling that have been the focus of many researches: empirical, regression and probabilistic models (Ogunlana, 1989; Raftery, 1991; Ashworth, 2004;). These have since been further refined into a number of cost estimating techniques. For most capital expenditures the widely used estimating techniques are; Expert Judgement, Analogy, Fuzzy logic, Artificial Neural Networks, Mean Least Square Regression, Method of Scales, the Parametric Methods, Engineering Estimates and Capacity Factored Estimation methods. Each of these techniques can be used with a certain degree of accuracy depending on the availability of model constructs or data. Some authors go further to group these techniques into algorithmic and non-algorithmic models (Shepperd, 1997). Algorithmic models utilise statistical data from past successful projects for example; Parametric models, Capacity Factored Estimation and Regression Analysis. Non-algorithmic models are not driven by predetermined mathematical steps; examples include Expert Judgement, Analogy, Neural Networks and Fuzzy Logic. In this section we discuss various techniques that are used for cost estimation. In our discussion we also consider their strengths and weaknesses under different conditions.

3.2.5.1 Expert Judgment

The estimation technique based on people with the knowledge of subject matter is known as the expert judgement. This method is based on knowledge acquired by experts using experience they gather from similar projects deployed previously. Because the judgement depends on individual opinion, it is subjective and is void of mathematical estimating relationships. If not carefully treated expert judgement is prone to bias hence liable to wrong estimates. There have been some endeavours to reduce subjectivity through recursive refinement of estimates by a number of subject matter experts who reach consensus anonymously. This process is called the Delphi method. The method works as follows: A facilitator gathers subject matter experts and provides them with project information. The experts are then asked to quietly make their estimates. The facilitator collects the estimates and distributes them anonymously to the experts who are given time to look at them and revise their own estimates. The process will continue iteratively until experts reach consensus. The whole idea behind this method is to minimise individual bias.

Although bias can be minimised some problems still persist. It is difficult to provide accurate estimates using expert judgement because this method bases its calculations on basic estimates which are not adjusted according to different peculiarities of planned project deployments. Because of various opinions that may produce different outputs given the same inputs, this method is highly uncertain and in terms of confidence rating it rates low. Experts' opinions are subjective hence estimates developed on them sometimes lack rationality and detailed analysis.

3.2.5.2 Analogy Estimation

The use of analogy is widely applied to estimate costs using observation reference to another similar project. Proponents of this method have tried to improve it by introducing task and inference decomposition. This is illustrated in Figure 3.8. A similar project which is a point of reference is used to transfer relative costs to a new project. The new project is referred to as a candidate. To start with, the task at hand is to generate the estimates. This is done through preparation, estimation and reviewing. Each of these has a number of subtasks as indicated in Figure 3.8. In the preparation task project understanding is valuable to start with. To understand the project various sources should be used to draw data for the model. The clear project understanding before inception creates good background to identify the candidate solutions. When all preparations necessary have been done the estimate can then be carried out. The estimation task is accomplished by two sub tasks which are illustrated in Figure 3.8 as transfer of relative costs and the estimate of the new costs. When estimates are ready they undergo a process of review. This includes the review of the estimated costs and determines the rationality of these costs.

Each of the subtasks in Figure 3.8, that is preparation, estimation and the review have inferences as the last level of their extended entity relationship (EER). Figure 3.9 illustrates the flow of subtasks inferences. The flow diagram shows how an expert using reasoning by analogy approaches the estimation processes. The approach involves a number of stages which range from obtaining data, searching for information, identifying right up to the final stage which is the estimated costs. Full details of this flow are clearly stated in Figure 3.9.

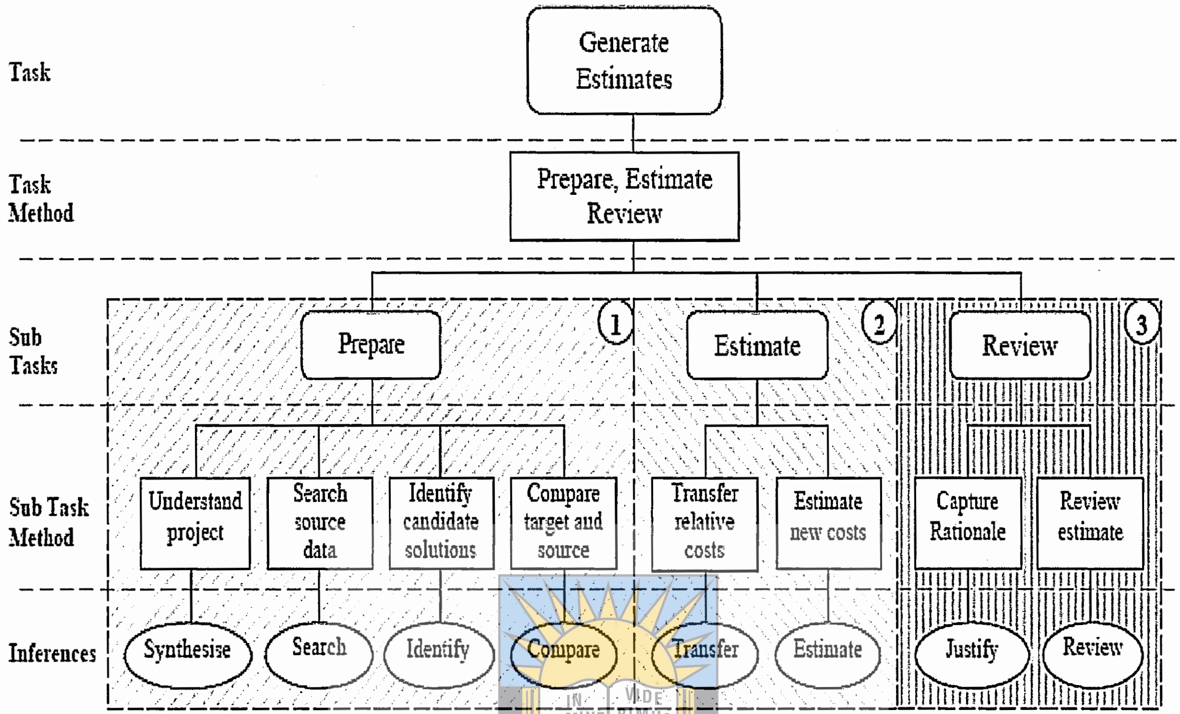


Figure 3.8: Task and inference decomposition for analogy based cost estimating (Rush, 2001)

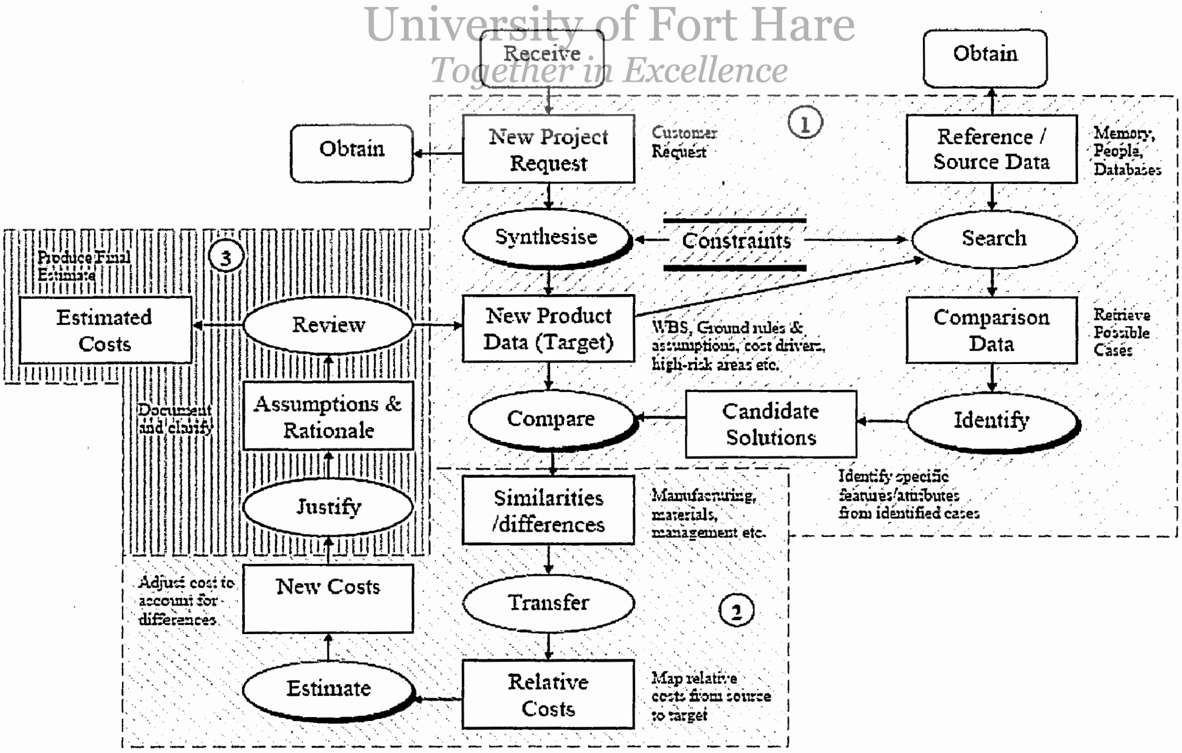


Figure 3.9: An inference structure for analogy based cost estimation (Rush, 2001)

Estimation by analogy has been used for various projects since it emerged. Its basis is to estimate the cost of a new system by using as its starting point the known costs for a similar existing system (Echard and Richey, No date). In addition it has proved quite useful in dealing with data that is not complex, however network deployment projects are each time becoming more complex and this is exacerbated by uncertainties surrounding some parameters (data sets). Further more, one can hardly find systems that are exactly the same. Hence estimates based on analogy technique are prone to a high degree of subjectivity when determining the similar and dissimilar technical parameters of the analogous system (Echard and Richey, No date). Because it is subjective, the level of uncertainty in estimates provided by it is very high and being a judgement process analogy method requires considerable expertise and experience. To overcome these weaknesses estimation by analogy has now roped in the concept of analogy by fuzzy.

3.2.5.3 Fuzzy Analogy

Some problems are very complex and would be difficult to solve using quantitative methods. When estimating costs experts use experience and subjective judgement such as approximately R 2 500 price or price is greater or equal to R 1 500. Linguistic terms are used to indicate cost range. This ambiguity presents difficulties in cost estimation as most techniques fail to deal with attributes that are measured using categorical quantifiers. Fuzzy analogy deals with such limitations as it is equipped to handle imprecise data. It uses the concepts of fuzzy logic and linguistic quantifiers. We begin by discussing these two concepts in this section.

3.2.5.3.1 Fuzzy logic

Fuzzy logic (FL) can be applied in two different ways; in a narrow sense and in a broad sense (Idri, 2001). The narrow sense of FL is the theoretical concept of fuzzy reasoning (Yun, 2005). Its broad sense consists of classes with continuous values and is based on classical set theory. In a real life situations most attribute costs fall within boundaries of two values; a minimum and a maximum. Within that interval, cost boundaries are not abruptly demarcated but tend to model a continuous graph. For example in the case of deploying wireless network infrastructure let us consider WiMAX Alvarion base station equipment for a rural kiosk. It is not easy to certainly say at what price the base station equipment can be considered too expensive (Yun, 2005). For instance if we say the Alvarion that costs R 6 500 is too expensive, what about the one that costs R 6 490 or R 6 450? The decision becomes subjective. Such questions which may have ambiguous answers are better responded to using categorical quantifiers. This involves setting an upper boundary above which the base station equipment can be said to be too expensive and a lower boundary which can be said not too expensive. Between those two boundaries there exist other boundaries in which it is not clear whether we can say too expensive or not. To limit this problem from cascading, grades can be allocated (Yun, 2005) to represent intervals. The basis of this approach is fuzzy set theory. Members of the fuzzy set have grades in the interval [0, 1] (Yun, 2005).

3.2.5.3.2 Fuzzy Sets

Let C be a set of cost objects and c_i the cost elements of C then $c_i \in C$. A class X can be derived that is characterised by a membership function $f_x(c_i)$ which establishes an association with each element of the universe of discourse C a real number in the range [0,1]. The set of elements associated with a grade in the interval [0,1] is known as a fuzzy set. Fuzzy sets are widely used in computational linguistics (Pathak, 2003). The fuzzy set is denoted by (Idri, 2001):

$$C = \int_0^X \frac{U_C(x)}{x} \quad (3.1)$$

Where $U_C(x)$ is the membership cost function and

X is the universe of discourse

The notion of fuzzy sets provides a convenient point of departure for constructing a conceptual framework of the costs of deployment that can be described using linguistic quantifies as we have indicated through examples above.

3.2.5.3.3 Linguistic Quantifiers

An innovative approach to such problems as given above is to apply the notion of fuzzy logic. Fuzzy logic is a methodology derived from further work on mathematical set theory. Mathematical set theory was brought to fame by a German mathematician Georg Cantor (Hrbacek, 1999). The great mathematician distinguished sets by their members or elements which have clear cut boundaries. This means that one is able to tell the difference or similarity between two members of the same set. As we have mentioned, a fuzzy set is characterized by a membership function, which associates with each point in the fuzzy set a real number in the interval [0, 1], called degree or grade of membership. The membership function may be triangular, trapezoidal, parabolic etc.

Figure 3.10 illustrates a representation of WiMAX Alvarion base station equipment cost categorised as too expensive. In Figure 3.10 (a), the translation of the function 'too expensive' is gradual showing that there are other values between the two extremes. This is one of the advantages of the fuzzy set approach. However this is not so with the classical set representation of the same function. The cost function is abrupt not showing a smooth transition from cheap to too expensive as shown in Figure 3.10 (b).

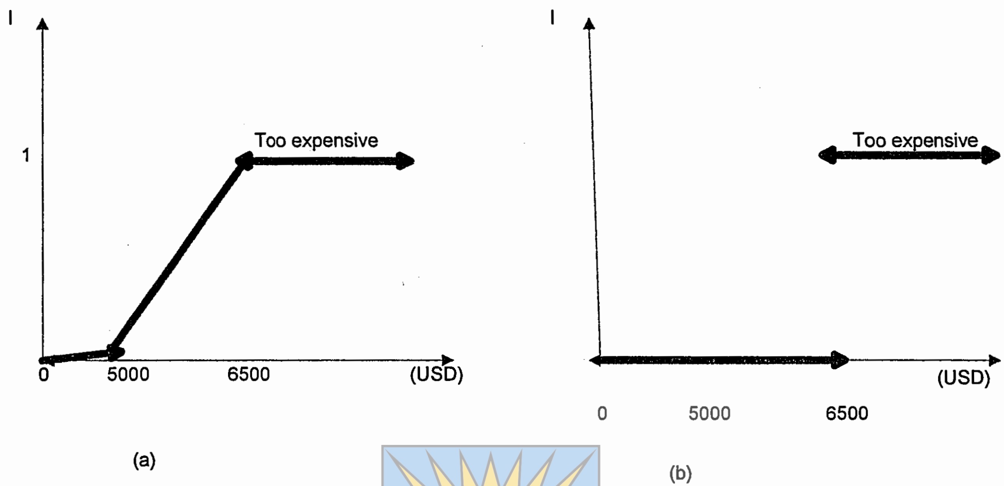


Figure 3.10: Linguistic value 'too expensive' represented in (a) Fuzzy set and (b) classical set (Adapted from Idri, 2001)

Fuzzy sets work with linguistic quantifiers such as 'too expensive', 'very cheap' e.t.c. paving the way to estimate costs from linguistic quantifiers. Yager (1996) identified three categories of proportional quantifiers:

i. Regular Increasing Monotone (RIM)

In RIM a fuzzy set P is defined by (Yager, 1996):

$$P = \begin{cases} P(0) = 0 \\ P(1) = 1, \quad and \\ P(x) \geq P(y), if\ x > y \end{cases} \qquad (3.2)$$

ii. A Regular Decreasing Monotone (RDM)

The RDM is defined by (Yager, 1996):

$$P = \begin{cases} P(0) = 1 \\ P(1) = 0, \quad and \\ P(x) \leq P(y), if\ x < y \end{cases} \qquad (3.3)$$

iii. A Regular Unimodal Quantifier (RUQ) (Yager, 1996):

$$\begin{cases} \exists(a,b) \in I, where\ a < b: \begin{cases} P(0) = 0 \\ P(1) = 1, \quad and \\ For\ y < a, P(x) \le P(y) if x < y \\ For\ y \in [a,b], P(y) = 1 \\ For\ y > b, P(x) \ge P(y) if x \ge y \end{cases} \end{cases} \quad (3.4)$$

3.2.5.4 Cost Estimation by Fuzzy Analogy

Estimating costs by fuzzy analogy undergoes three steps; identification of cases, retrieval of similar cases and case adaptation.

3.2.5.4.1 Identification of Cases

The identification step deals with the selection of attributes that represent the cost estimation of a project. If for instance we want to estimate costs for wireless network infrastructure the selected attributes must be relevant (Idri, 2001) for the estimates of network deployment. At times some very important attributes are left out because no historical data exists, that show them interacting with other attributes. This has been a cause for concern and has provoked the researchers' fraternity. Some authors have suggested the use of brute force (Idri, 2001) search method to select attributes. Others like Briand et al (1998) favour the use of t-test to do the attribute selection. Which ever method is applied the end result should be a proper selection of attributes. Attributes can be measured numerically or categorically. If the attributes consists of categorical data they first undergo fuzzification by a function which can either take the value of 0 or 1, this has been discussed under linguistic quantifiers.

3.2.5.4.2 Retrieval of Similar Cases

This step is very important as it involves searching for measures that can be used for similarity. All characteristics that make projects similar are retrieved. Since attributes can be either numerical or categorical, different methods are used for retrieving similarity. Two methods that have been used for this task are the Euclidean distance if attributes are numerical and the equality distance if they are categorical. However these have been criticized (Idri, 2000) especially when the data consists of fuzzy sets. For fuzzy sets individual distances of linguistic variables (V_j) which describe the two similar projects P_1 and P_2 is represented by (Idri, 2000);

$$d_{v_j}(P_1,P_2) = \begin{cases} \max\min\left(\mu_{A_k^j}(P_1), \mu_{A_k^j}(P_2)\right) \\ max-\min aggregation \\ \sum_k \mu_{A_k^j}(P_1) \times \mu_{A_k^j}(P_2) \\ sum-product\ aggregation \end{cases} \quad (3.5)$$

Where v_j are linguistic variables describing projects.

P_1, P_2 and A_k^j are the fuzzy sets associated with V_j, and

$\mu_{A_k^j}$ are the membership functions representing fuzzy sets A_k^j.

In order to get the distances $d_{v_j}(P_1,P_2)$ is aggregated (Idri, 2001) using RIM (equation 3.5).

More information on the appropriate choice of the RIM linguistic quantifier can be found in (Idri, 2001).

3.2.5.4.3 Case Adaptation

In this step the costs for the new project are estimated using historical data from similar projects (Idri, 2001). The question is how many similar projects can be used in the process? The number is not important, what is important is to find those projects with similarities. Case adaptation produces the cost estimates of the new project by using the weighted mean of the costs of all similar projects in the dataset. The following equation is used for this task (Idri, 2000):

$$C(NP,P_i) = \frac{\sum_{i=1}^{N} d(NP,\ P_i) \times C(P_i)}{\sum_{1=i}^{N} d(NP,P_i)} \quad (3.6)$$

Where:

$C(NP, P_i)$ is the estimated cost of the new project.

NP is the new project.

P_i are the projects in the data set.

$C(P_i)$ are the costs of the projects in the data set and

$d(NP, P_i)$ are membership functions that express the truth value of the fuzzy proposition that NP and P_i are similar (Idri, 2001).

A number of cases can arise with respect to d (NP, P_i) (Idri, 2001):

- If d(NP, P_i) is null then it implies that P_i does not influence the estimated cost of NP.
- If d(NP, P_i) is equal to 1 this implies P_1 influences to the maximum the estimated cost of NP.
- If d(NP, P_i) is between 0 and 1 then this implies that P_1influences partially the cost of NP.
- If all d (NP, P_i) are equal to 0 then it implies that we cannot estimate the cost of NP using the data set. This happens when if all projects in the data set are totally different from NP.

3.2.5.5 Artificial Neural Networks

In cost modelling data generation can sometimes produce constraints. These can be better exploited using artificial neural networks (ANN). The origins of neural networks (NN) can be traced to various studies that ought to mimic human brain behaviour. Their applications are so diverse covering many domains (Hykin, 1998). The ANN was actually inspired by the architecture of the biological neural networks (Tronto, 2006) which are based on the structure of the nervous system. Today NN are being used successfully in estimating various project costs. For detailed information on NN refer to (Levin, 1993) and (Levin, 1996). The most distinguishing trait of the neural cell is that it learns from experience (Lippmann, 1988) and adapt to a new situation. Figure 3.11 shows the sketch of a biological neural cell. The dendrites (input connections) link the nucleus with other neurons. Each neuron has an axon that transmits "electric potentials" (Pathak, 2003: 154) to other neurons connected to it. The electric potentials form messages that are passed to relevant neurons to trigger a suitable response.

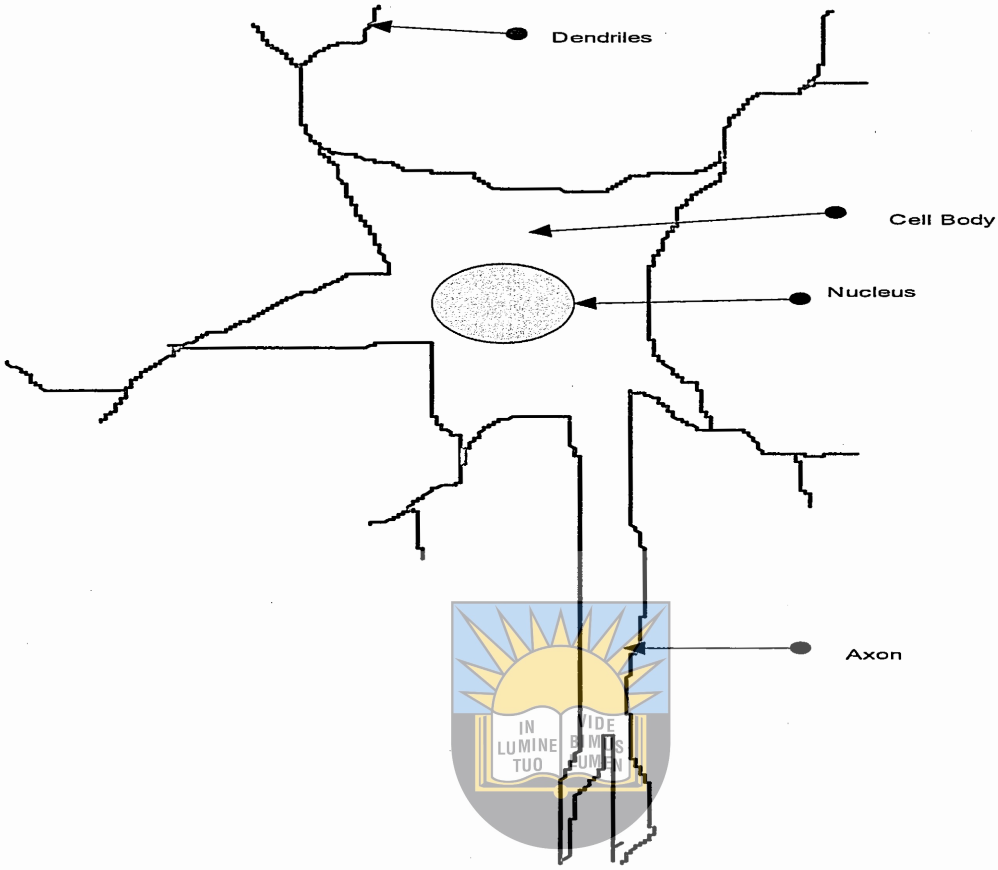


Figure 3.11: The biological neuron (Pathak, 2003).

The ANN unit (figure 3.12) resembles the biological neuron. It has "several input paths corresponding to the dendrites" (Pathak, 2003; 154). Its combined inputs are called weighted sum and are sent into the neuron for modification by a function. If the sum of the input signals surpasses a certain threshold, the neuron sends an action potential at the axon hillock and transmits this electrical signal along the axon (Bio, 2006). Weights are given as real numbers that define input connections.

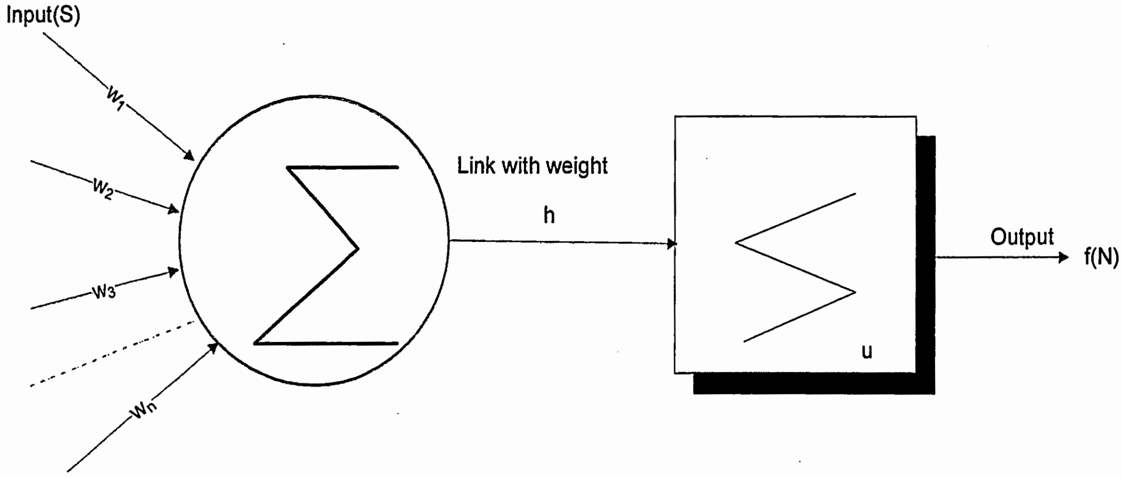


Figure: 3.12: A McCulloch and Pits neuron (Tronto, 2006)

The modified values are given as outputs and an algorithm (Pathak, 2003) is often used to train the neuron to respond to different new environments given the various inputs. The link between neurons is either strengthened or weakened by experiences that are obtained during training (Pathak, 2003; Andrea, 2000; Nouir, 2006). Algorithms that are used to train the neural networks are called learning algorithms. These algorithms are responsible for searching the solution space for a more optimal cost function: C: F→R. The learning process entails using "a set of observations in order to find $f^* \in F$ which solves the task at hand in an optimal way (ANN, 2008)." The cost function to be applied is dependant upon the nature of the task i.e. performance task or classification would normally require a sigmoid (Narayan, 1997) function. There are basically two widely used sigmoid functions in NN; the first one represented in figure 3.13 (a) is simply known as the sigmoid function[2] while the other represented in figure 3.13 (b) is known as the symmetric sigmoid function. The difference between the two functions lies in their output range; the sigmoid function's output lies between 0 and 1while the symmetric sigmoid has an output in the range between -1 and 1.

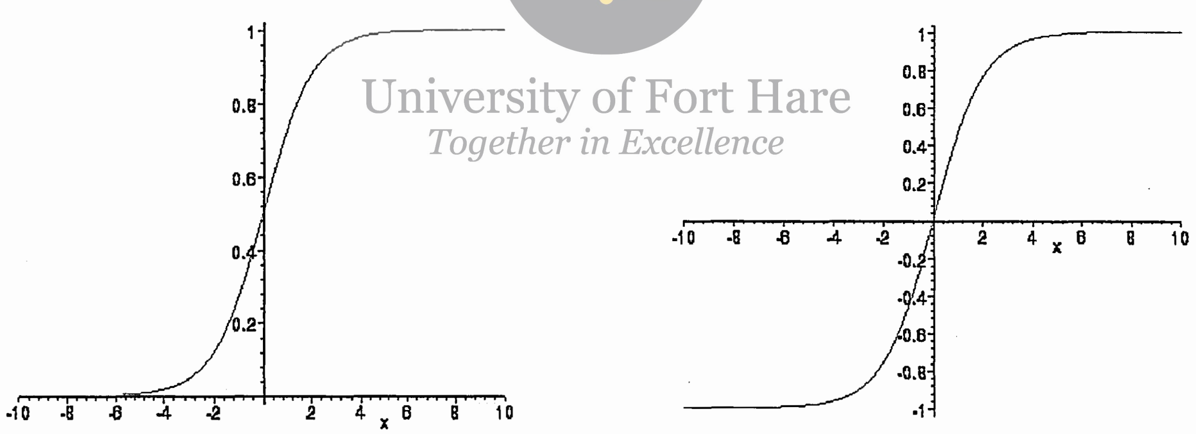


Figure 3.13: (a) Sigmoid cost function (Narayan, 1997) (b) Symmetric sigmoid cost function (Narayan, 1997)

One of the constraints in modelling costs is the future price increments which can be unknown for a certain future period. There are basically two approaches to deal with this, the first is known as a hard constraint (Abu-Mostafa, 1990; Abu-Mostafa, 1993). To deal with hard constraint in ANN entails including the possible (fixed) constraints during ANN training, as weights. For example a NN can be given an initial point of zero meaning that it will produce a forecast of zero when there are no past observations. Jin et al (1994) suggested

[2] A sigmoid function is a mathematical function that produces a curve having an "S" shape.

that a neural network must at least have one fixed point. The second is known as a soft constraint (Abu-Mostafa, 1995) and involves guiding the NN towards a solution but not actually giving the final solution. Its ability to handle noisy data and imprecise data makes it a promising method.

The neural network cell is trained using historical data to produce estimates whose percentage error is negligible. The modeling process when using neural networks involves the following stages: data acquisition, representation of the problem and analysis, architecture determination; learning process; training and testing for generalization (Wu, 1993). The learning process uses three types of learning (Kwok, 1997; Harp, 1991); Supervised learning, unsupervised learning and reinforcement learning. The objective of the learning process is to minimize the cost function. Minimizing the cost function is a way of making the cost estimation error decline. The cost function is represented by the equation (Kwok, 1997; Harp, 1991):

$$E = \frac{1}{2}\sum_{p=1}^{N}(y_p - d_p) = \frac{1}{2}\sum_{p=1}^{N} e_p^2 \qquad (3.7)$$

Where y_p is the p^{th} output value calculate by the network and d_p represents the expected value.

Minimizing the cost function is a long process that involves lengthy training of the NN using any of the learning processes mentioned above. We briefly discuss in the following sections some of the learning processes including a well known training algorithm; the back propagation.

3.2.5.5.1 Supervised Learning

Supervised learning is also called associative learning deriving the term from its ability to associate inputs provided with various matching patterns for outputs. The difference between the output and the desired vector is fed back into the network. Figure 3.14 shows the architecture of supervised learning (Technologies tutorials, 2007).

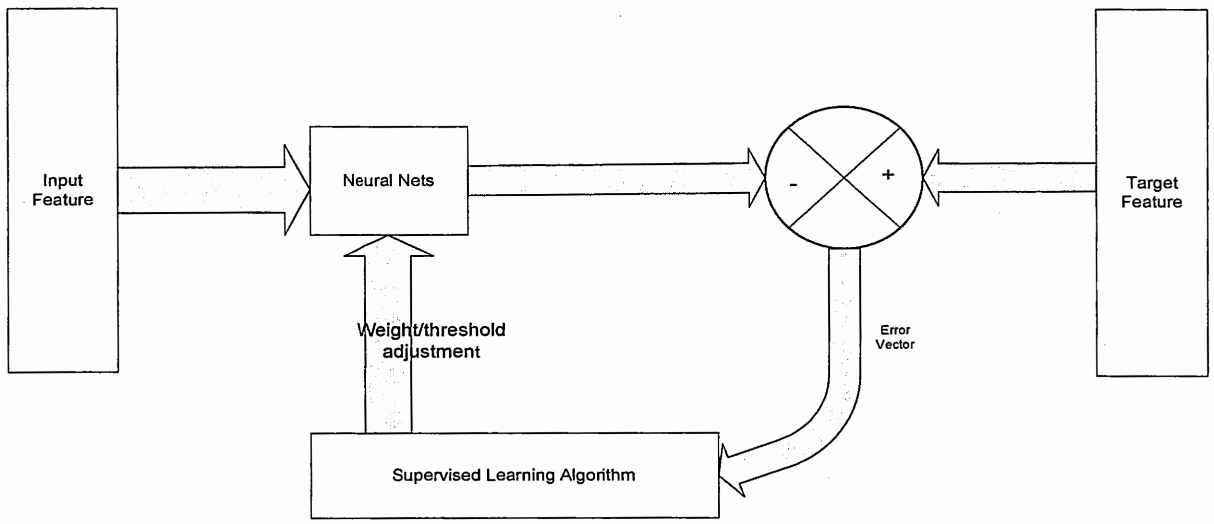


Figure: 3.14: Supervised learning. (Adapted from Technologies tutorials, 2007)

3.2.5.5.2 Unsupervised Learning

Unlike the supervised learning this paradigm does not have matching input and output patterns; instead the output unit is trained to respond to different patterns of inputs (Technologies tutorials, 2007). It is the system that finds the characteristics of the input pattern and finds suitable output patterns. There is no prior classification of inputs and the cost function for the output.

3.2.5.5.3 Reinforced Learning

In this type of learning cost functions are subjected to a learning algorithm that classifies input and output matches as bad or good basing on the environmental conditions and iteratively adjust weights until an optimal cost function is found.

3.2.5.5.4 Training Process

The training of the NN is an iterative process that involves the exploration of inputs and outputs to obtain the desired outcomes. Figure 3.15 is a representation of the ANN training process. Inputs are introduced into the NN as computed keys[3] to undergo analysis. The output from that process is compared to the desired results and the mean square error is calculated. An algorithm is then used to examine the error and adjust the weights using historical data. The process of adjustment of weights continues until the desired vector (predicted keys) has been reached. One of the algorithms commonly used to examine the error is the back

[3] Computed keys are inputs that have been modified by weights and through a training algorithm.

propagation algorithm.

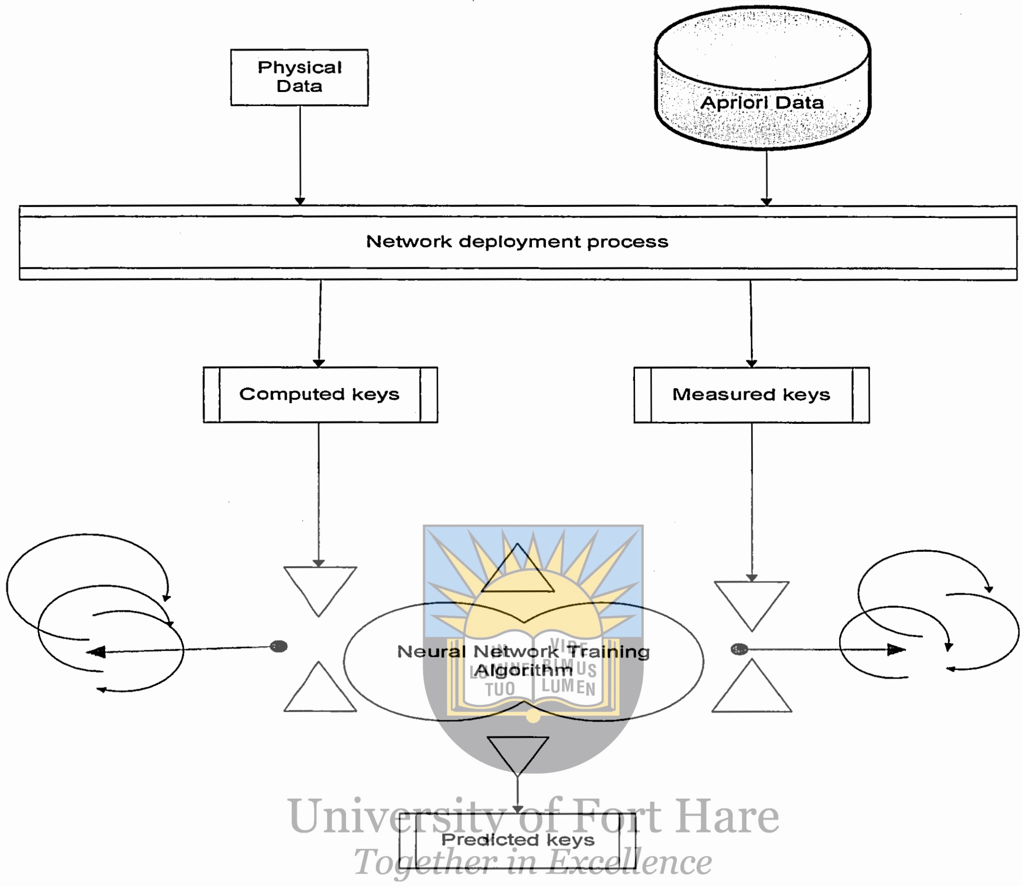


Figure 3.15: ANN training process. (Adapted from Nouir, 2006)

3.2.5.5.5 Back propagation algorithm

Back propagation is an algorithm that is used to adjust weights during training of the NN. This algorithm calculates the error by taking difference between the calculated result and the target value. The error is then fed back into the network and weights are adjusted accordingly. In order to have an optimal cost function the algorithm must minimize the mean square error in equation (3.6). The use of the back propagation algorithm is to minimize that error. The outputs are the functions of weights *w* which are generated for every neuron (Ghahramani, 2001). Minimization of the error can be obtained through the use of the following equation (Echard and Richey, 2002):

$$\nabla E(w) = \frac{\delta E(w)}{\delta w_i} = 0, \qquad \text{for all i} \qquad (3.8)$$

For the update rule in back propagation algorithm (Echard and Richey, 2002) we have:

$$w(t+1) = w(t) + \nabla w(t) \qquad (3.9)$$

Where:

$$\nabla w(t) = -\vartheta \frac{\delta E(t)}{\delta w(t)} \qquad (3.10)$$

In this equation ϑ represents the learning parameter.

During training process the great concern is the level of error in the output cost function. There are basically two cases that can occur; that the error is above a certain threshold or below it. Since we are interested in one of those two states the one which is below the threshold, the training process needs to be modeled to determine whether the probability of error (P_E) is greater than or less than the threshold. If the error is in the acceptable levels then the error is said to be negligible. We can model this using the Markov two-state model. Let the two states be represented by the set (Pathak K and Agawal R, 2003):

$$S = \{ac, unac\} \qquad (3.11)$$

Where: ac represents the acceptable error levels and

unac represents unacceptable error levels

The iteration during the training process produces a set of transition probabilities a_{ij}. These are conditional because they depend on the input given. For a two state model there are four probabilities of interest. Let S_t and S_{t+1} denote the state of the error during the first and second (at time t and at time t+1) iterations. The four probabilities are (Pathak K and Agawal R, 2003):

$$a_{ac}(t) = Pr\{S_{t+1} = ac | S_t = ac\} \qquad (3.12)$$

$$a_{(ac)(unac)}(t) = Pr\{S_{t+1} = unac | S_t = ac\} \qquad (3.13)$$

$$a_{(unac)(ac)}(t) = Pr\{S_{t+1} = ac | S_t = unac\} \qquad (3.14)$$

$$a_{(unac)(unac)}(t) = Pr\{S_{t+1} = unac | S_t = unac\} \qquad (3.15)$$

According to Markov chain this can be written as (Pathak K and Agawal R, 2003):

$$A(t) = \begin{bmatrix} a_{(ac)(ac)}(t) & a_{(ac)(unac)}(t) \\ a_{(unac)(ac)}(t) & a_{(unac)(unac)}(t) \end{bmatrix} \qquad (3.16)$$

Where :

A(t) is the state transition matrix.

The error probability can then be computed using MATLAB (see appendix A). We need to remind that for the error to be in an acceptable level the error probability should be less than the error probability in unacceptable levels. When the program is executed it gives probability error as 0.289, depending on the level of confidence set, it may be necessary to minimize the error.

3.2.5.5.6 The Prediction Process

When inputs are passed through the training function they have their weights adjusted producing the predicted keys. The back propagation algorithm calculates the error and compares it with the measured keys as shown in Figure 3.16. The process goes on iteratively until the error has been minimized to the required levels.

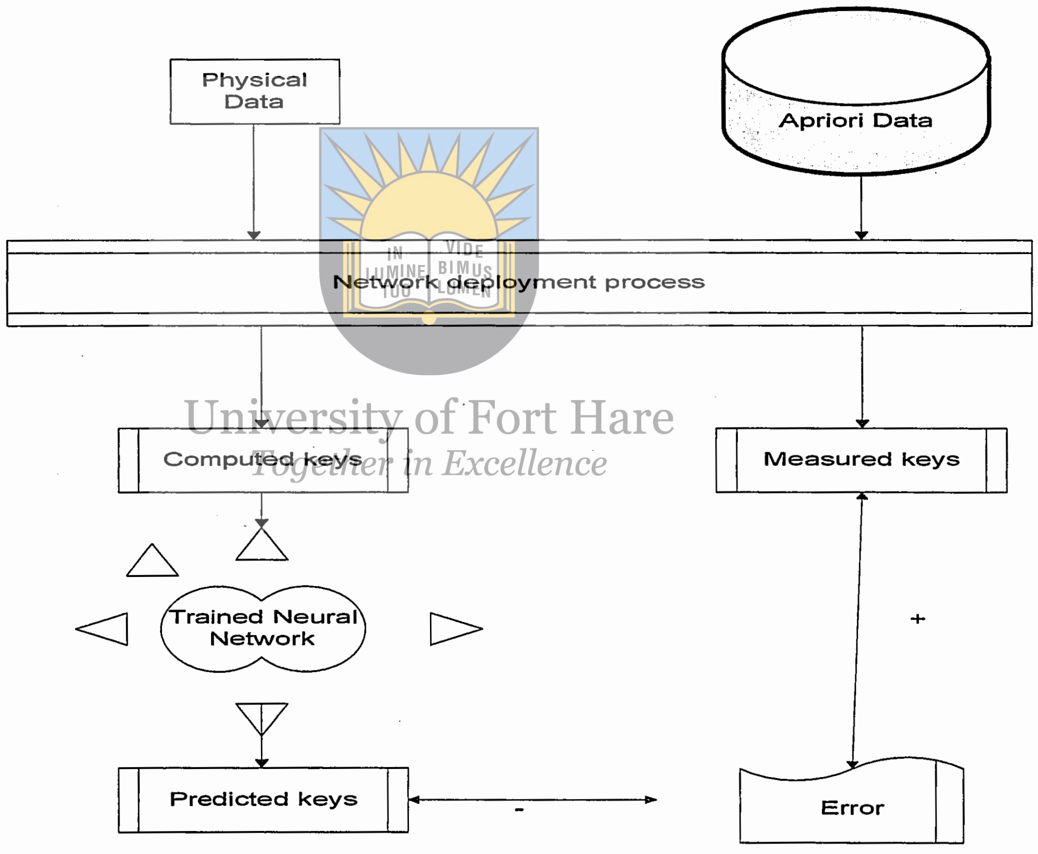


Figure 3.16: Prediction process (Nouir, 2006)

In Figure 3.17 we show a typical neural network for estimating wireless network infrastructure costs. In the figure cost components are inputs which are channeled into the Hidden layer through the input layer. The transformation function in the Hidden layer[4] then transforms (Asakawa, 1994; Boussabaine, 1996) the cost components and calculates the

[4] Hidden layers are layers additional to the input and output layers.

output. The output produced by the network is then compared to the target output and the mean error is minimized during the process.

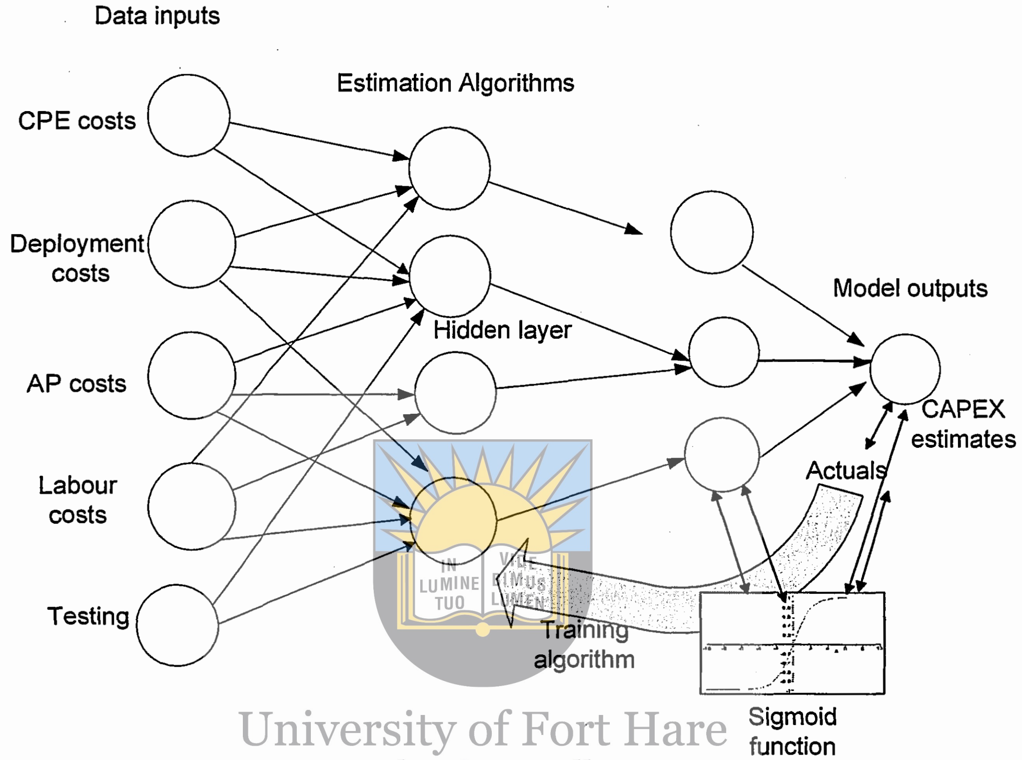


Figure 3.17: NN with multi layer perceptron to estimate costs of network CAPEX (Adapted from Asakawa, 1994)

The multi layer perceptron neural network (MLPNN) is represented by the equation (Asakawa, 1994):

$$y_p = F_0\left(\sum_{j=0}^{N} w_{jp}^{H}\left(F_H\left(\sum_{i=0}^{N} w_{ij}^{I} x_i\right)\right)\right) \quad for\, p = 1, 2, \ldots, N \qquad (3.21)$$

In the equation:

w_{jp}^{H} are the weights from neuron j in the hidden layer to the pth output neuron,

x_i is the ith element in the input layer,

F_H and F_0 represent the activation functions in the hidden and output layers respectively and,

w_{ij}^{I} are the weights from neuron j in the hidden layer.

Appendix B shows the MATLAB program that simulates the training process of the perceptron. The simulation shows that large training sets are required to obtain acceptable results. Some of the results are shown in Figures 3.18-3.20.

The number of training sets (samples) needs to be large (Wolpert, 1994, 1996a, 1996b,) for the perceptron to learn and be able to give correct estimates. When executing the above program we used three numbers selected arbitrarily. We just selected 10, 50 and 2000. The curved line is the desired level of estimating. If points are further from the curve then it means that the perceptron has not gained much experience to give accurate estimates (Freeman, 2004). We note that in Figure 3.18 the points are very far from the curve because the number of training samples is very low. As the number is increased, the points move closer to the curve. This can be noted in Figure 3.20 that the number of samples is very large and the points are right on the curve. The perceptron has acquired enough experience to give accurate estimates.

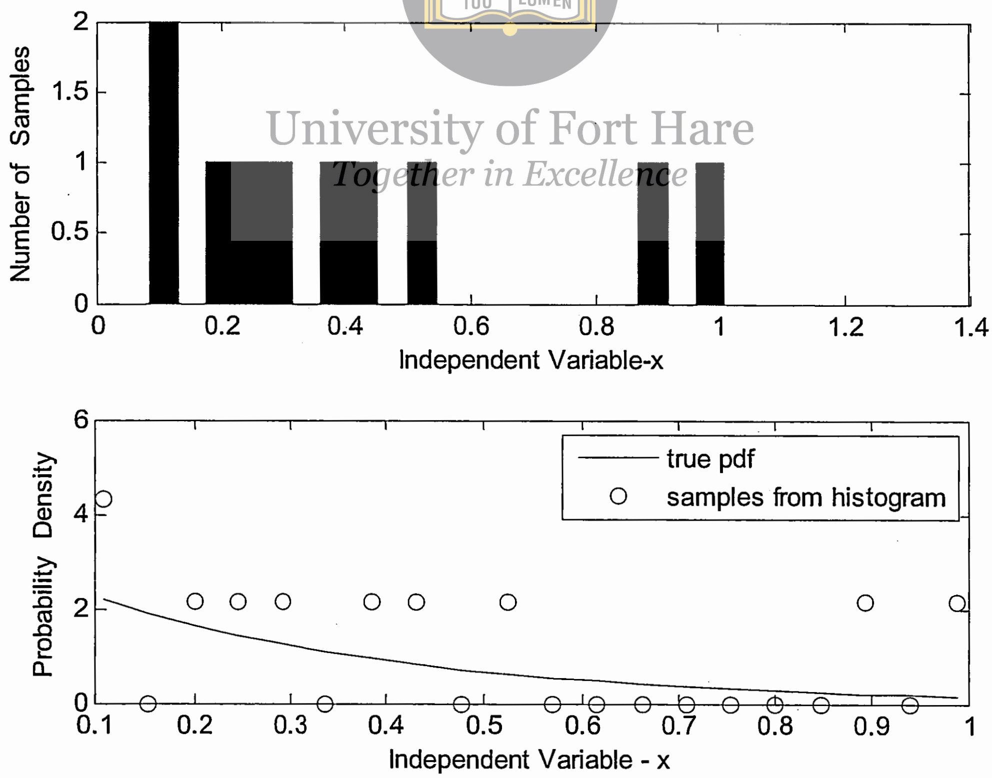


Figure 3.18: Result for NN training when n=10

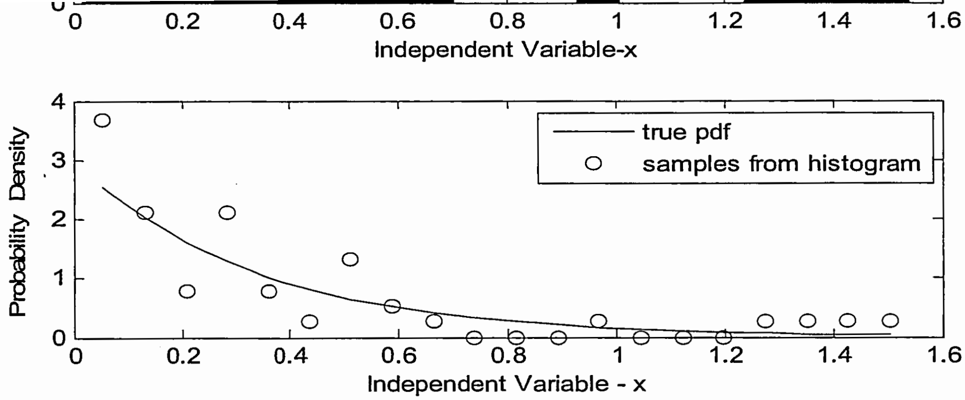


Figure 3.19: Results for NN training when n = 50

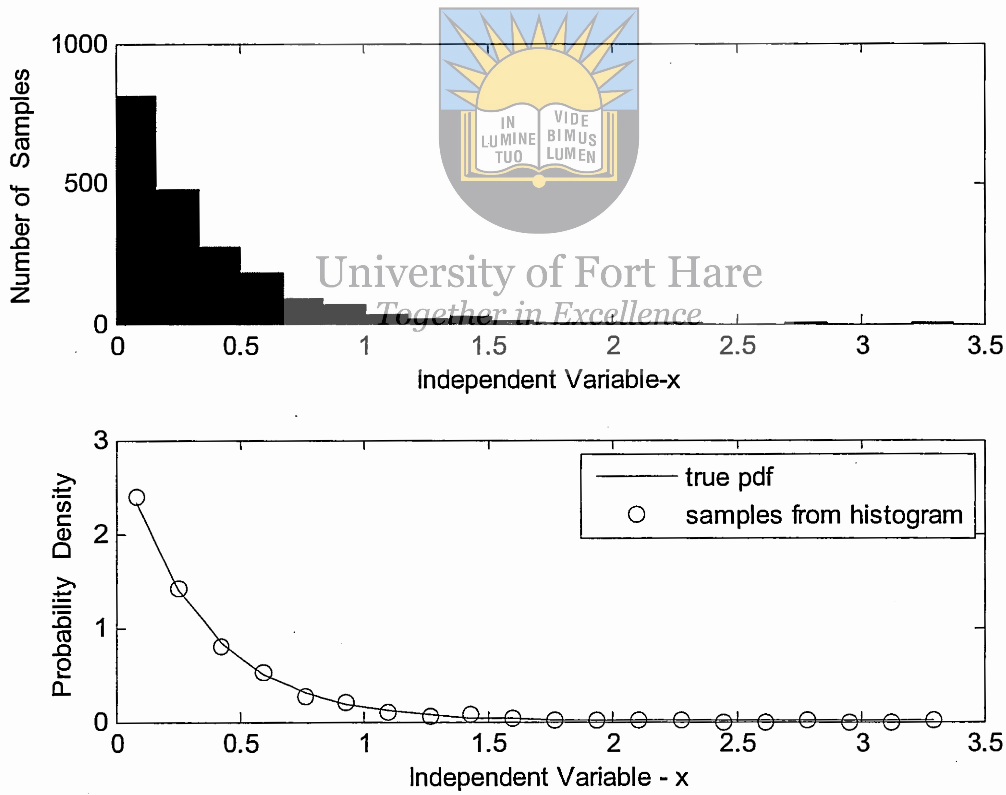


Figure 3.20: Results for NN training when n = 2000

3.2.5.5.7 Limitations of Neural Networks

Neural networks may need longer processing time to process larger information because of training time. Since ANN's accurate cost prediction depends on a very large data set it is unrealistic in our rural regions as data sets for the costs variables is small. The performance of ANN is strongly determined by the data hence if data available is not sufficient; it may not be the right choice. To accurately train the network a big data set is needed which further elongates processing time (Freeman, 2004). In addition to chose a sufficiently complex network structure to train to a desired mapping for function approximation is a big challenge. The complexity of network here refers to network parameters for example the number of neurons or number of layers needed for training. There is also little benefit in terms of sensitivity analysis of the relationships between inputs and outputs. Iterative NN may also be oscillatory producing more complications and instability of the model (Cohen, 1992; Blum, 1992).

3.2.5.6 Mean Least Square Regression

Mean least square (MLS) Regression models use historical data (Layer, 2002) to establish the optimum relationship between the input values and output values (DOE, 1997). The regression line y on x gives the average value of y for a given value of x, so in certain circumstances it can be used to predict missing values. This is known as interpolating from the given information. The realization of optimality is achieved through the use of regression coefficients. The following equation represents a multiple regression (Layer, 2002):

$$y = c + b_1x_1 + b_2x_2 + \cdots + b_kx_k \qquad (3.22)$$

Where c is a regression constant,

$b_1, b_2, \ldots, b_k$ are regression estimates and

$x_1, x_2, \ldots, x_k$ are independent variables and y is the dependent variable.

Although not all processes are linear in nature, the application of MLS is based on the fact that at different points in small ranges any process approximates a linear model. As compared to other methods MLS are efficient in obtaining good results even with small data and their statistical intervals for prediction are easier to construct and interpret.

Nevertheless MLS method is limited because of sensitivity to outliers as it has poor extrapolating properties. As the range of the data increases it becomes difficult to linearly fit data into a model. To explore non linear processes more advanced cost estimation methods are needed that enable even the modelling of complexities of the model processes.

3.2.5.7 *Parametric Methods*

The origins of parametric models date back to World War II (Valerdi, 2005). The war caused an exponential growth of aircraft demand that necessitated cost estimation methods that were quick and reliable. Wright T.P. (Valerdi, 2005) suggested a statistical estimating method in 1936 which provided a system of equations that were used to predict the cost of aircraft over long production runs. His contribution was published in the Journal of Aeronautical science and became to be popularly known as the learning curve (Valerdi, 2005). Parametric models are known as algorithm models as these are built on mathematical algorithms. The algorithms define sets of steps in relating the model parameters together. They use cost estimating relationships (CERs), which are a mathematical representation that associates a number of functional cost relationships (online, 37).

Let us consider the deployment of a wireless network for example. The system to be deployed consists of parameters and costs elements. These two are used in relationship equations to establish various estimates. CERs are logically used to predict unknown functional costs. Modelling CERs entails gathering low level data about the basic cost drivers that significantly influence the total costs. To minimize significant errors on the resultant estimation, low level data is normalized after collection. Normalization of data guarantees the closeness to the actual costs of the project under consideration. Parametric models rely so much on physical attributes and their relationships to have component costs aggregated. From that premise if there is inadequate data it can seriously limit their use. The basic parametric estimation method is commonly known as the method of scales.

3.2.5.8 *The Method of Scales*

The method of scales is based on various attributes of the components of a model whose costs are being estimated. These attributes may include size of tower, range, bandwidth and capacity in the case of network deployment. The assumption here is that if there has been a recent deployment of a network and we would like to deploy another with similar features we simple establish proportionality costs. This implies that average costs of deploying a network increases with capacity or size. Let c_1 be a variable representing the network size, and C be the total cost of deploying the network. We can then linearly interpolate using equation (Hendrickson, 2000):

$$C = a + b_{c_1} \qquad (3.23)$$

Where a, and b are positive constants drawn from historical costs (Hendrickson, 2000). Estimating costs using method of scales produces a linear graph.

However, most cost models tend to be modelled through nonlinear cost relationship (Hendrickson, 2000) between network deployment costs and network size or capacity. The linear model can be improved when it is combined with non-polynomial terms. For example, consider the following cost function that is linear in the parameters c_1, c_2, and c_3, but nonlinear in the s data (Hendrickson, 2000):

$$C = c_1 + c_2 e^{-s} + c_3 s e^{-s} \tag{3.24}$$

We can form a design matrix using MATLAB where each column represents a variable used to predict the costs and each row corresponds to observations of those variables. The small code below shows how we can form the design matrix.

```
% Enter s and C as columnwise vectors
s = [0 0.3 0.8 1.1 1.6 2.3]';
C = [0.6 0.67 1.01 1.35 1.47 1.25]';
% Form the design matrix
X = [ones(size(s))  exp(-s)  t.*exp(-s)];
% Calculate model coefficients
c = X\C
```



```
c =
   1.3983
 - 0.8860
   0.3085
```

The values of c which is the design matrix can now be substituted into equation 3.24 in place of c_1, c_2 and c_3. Therefore, the model of the data is given by the following equation:

$$C = 1.3983 - 0.8860e^{-s} + 0.3085se^{-s} \qquad 3.25$$

Where C is the cost and s is the size of the network being deployed.

However the method of scales ignores various complexities as evaluation is determined by analogy with completed similar deployments hence it falls on the boundary between the analogy and the parametric (Duverlie, 1999). One of the major disadvantages of this method is the assumption of a linear relationship between the value of the considered parameter and the cost. Most real world problems are nonlinear making the accuracy of the method of scales unreliable.

3.2.5.9 The Engineering Estimation Method

The engineering method also known as the bottom-up builds up a system's functional (i.e., planning, analysis, development, testing, training, deployment, operations, and maintenance) and material costs (i.e., hardware/software acquisition) using engineering estimates of reliability, maintainability and component cost characteristics (Clark and Lorenzoni, 1997). To use the method one needs to make a breakdown for example of the Internet infrastructure into lower level components. The task will then be to make an estimate of each component. To successfully use this method it requires an analyst who has extensive knowledge of the phenomenon being modelled, to be able to break the system into lower level components and estimate costs for each component. When making estimates for each component, the analyst is at liberty to use other estimation methods in the process. Figure 3.21 illustrates the engineering method.

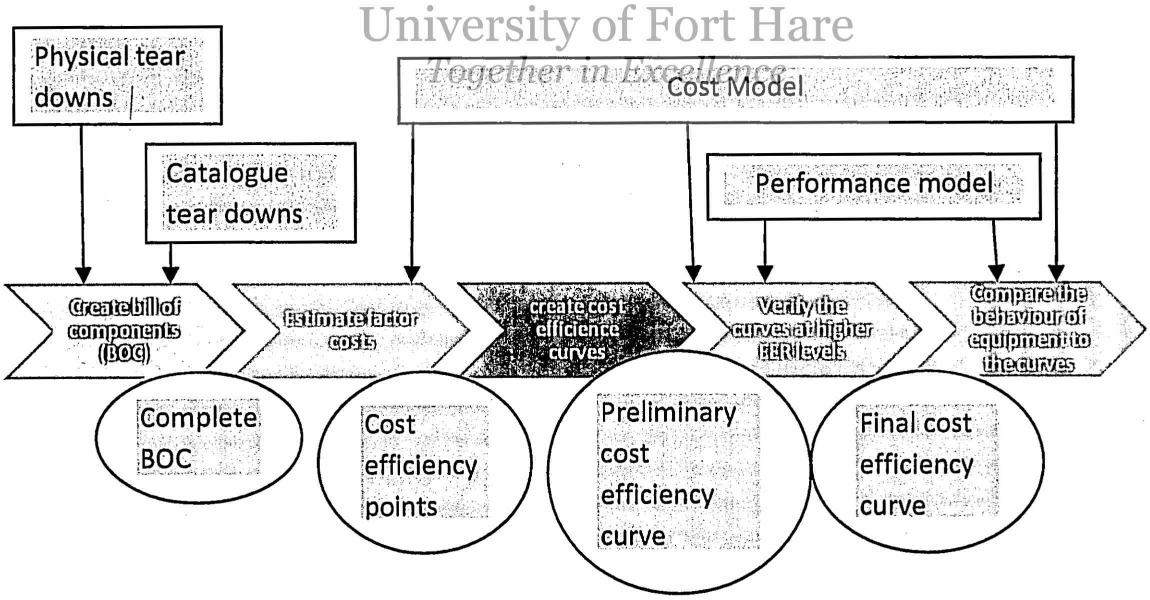


Figure 3.21: Engineering method (Clark and Lorenzoni, 1997).

In breaking down the system to its low level components the analysts uses tear downs analysis (Clark and Lorenzoni, 1997). These are categorised into two; the physical tear downs and the catalogue teardowns (Clark and Lorenzoni, 1997). Physical tear downs process is whereby the analyst obtains equipment costs directly from vendors piece by piece. Whereas the catalogue tear downs involves the analysts using the published catalogues from different sources.

Figure 3.22 illustrates the phases of engineering analysis. In the first phase the analyst estimates costs based on established technologies and their established efficiency standards. Established technologies and new efficiency standards make the basis of cost estimates in the second phase. The analyst in the third phase considers cost estimates using new technology as well as new efficiency standards.

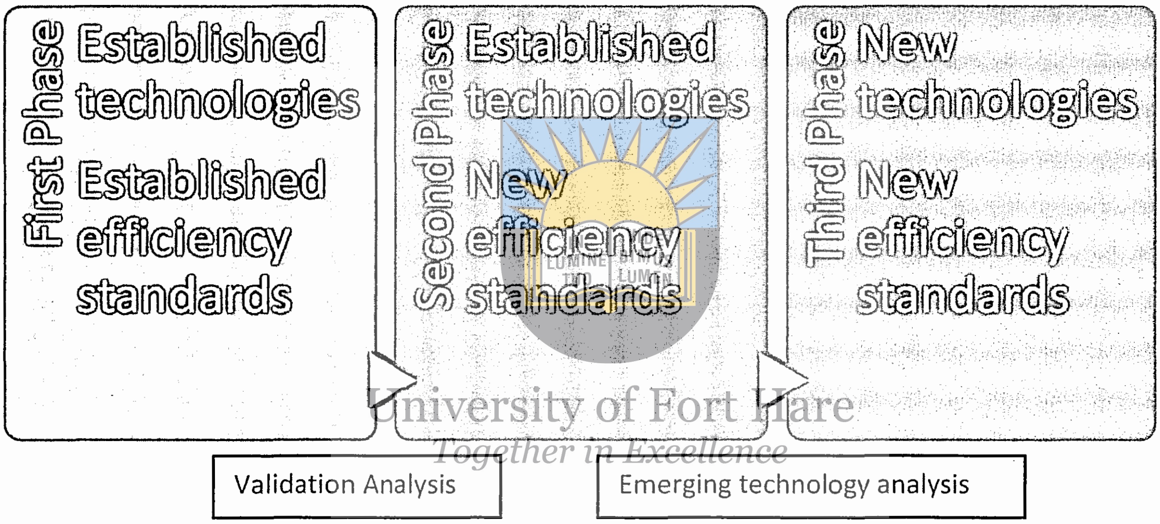


Figure 3.22: Phases of engineering Analysis (Clark and Lorenzoni, 1997)

This method is suitable when the project is already on and there has been a prototype. Engineering estimation greatly reduces subjectivity and uncertainty levels. It is however expensive and needs a lot of time (Clark and Lorenzoni, 1997). In addition to that because the method requires an analyst with extensive knowledge of engineering analysis, this may not be available thereby limiting the use of the method.

3.2.5.10. Capacity Factored Estimate

The capacity factored estimate (CFE) relies on an algorithm represented by the "nonlinear relationship between capacity and cost" (Larry, 2003: 23). This relationship is represented using the following equation (Larry, 2003):

$$C_{PP} = C_{KP} \times (\frac{CPP}{CKP})^{\alpha} \qquad (3.26)$$

Where:

C_{PP} is the estimated cost of the new project,

C_{KP} is the cost of the known project similar to the proposed project,

CPP is capacity of the proposed project,

CKP is the capacity of the similar project whose costs are known and

$\propto$ is the scaling factor.

The basis of the CFE hinges on using the costs of a known project with a certain capacity to estimate the cost of the proposed project with a different capacity. This means that the cost of new infrastructure model is derived from the cost (Larry, 2003) of a similar infrastructure deployment with a known capacity. The logarithm relationship is sometimes known as the "six-tenths-factor rule" (DOE, 1997:20). According to this rule, if the cost of a given unit of a certain capacity is known, the cost of a similar unit with X times the capacity of the first is approximately $(X)^{0.6}$ times the cost of the initial unit (DOE, 1997:20). However we can still vary the scaling factor to simulate the cost of various technologies under similar environment. The results from such simulations would help to make sensitivity analysis of the technologies. Reliance on the scaling factor 0.6 is usually done when no other information is available (Larry, 2003). One of the positive contributions of the CFE during the model's design phase is that it clarifies how different parameters influence the model's costs. CFE is a good option when not all information is available. This however may negatively impact on the model as some of the parameters that were not accounted may tend to be very important.

3.2.6 Benefits of Cost Estimation

Cost models are very important tools in research as well as in business as they provide a framework for making analysis e.g. cost sensitivity analysis, contingency analysis of various economic trends and technologies. Contrary to the use of cost models is the unstructured expert judgement. This approach may yield different outputs from the same inputs since it is subjective. However cost models produce the same outputs when they are given the same inputs showing great consistency. Other benefits are (DOE , 1997:22):

- The consistency of response inherent in cost models enables the analyst to make comparisons among alternatives
- The ability to compare on a consistent basis is one of the most attractive features of cost models

3.2.7 Cost Estimation Challenges

Although cost estimation using various cost models has a number of advantages there are challenges to their implementation. Producing a reliable cost estimation model requires; a lot of historical data, availability and willingness of experts of a particular domain of which the cost estimate is derived and the ability to identify and plan for risks. It is however unfortunate that in the best of circumstances we may be found wanting in any of the above mentioned constructs of building a good cost model. A number of challenges support this assertion. Those challenges may lead to bad estimates characterised by poor assumptions, inadequate data and inappropriate estimating methodologies (GOA, 2007). Figure 3.23 illustrates some of the challenges.

The success of cost estimation is dependent on the experience of those constructing the model and on historical data available. However lack of experience has emerged the greatest challenge. Inexperience may lead to a failure to select appropriate methods and sometimes making unrealistic assumptions as illustrated in Figure 3.23. In addition over optimism is equally a danger, it is bound to lead to a compromise in risk analysis. Such a compromise may expose the cost estimation model to unprecedented risks. In cases where historical data for the model is not available analysts usually make estimations using expected values. This may seem a plausible solution but it introduces inherent uncertainties into the estimation model.

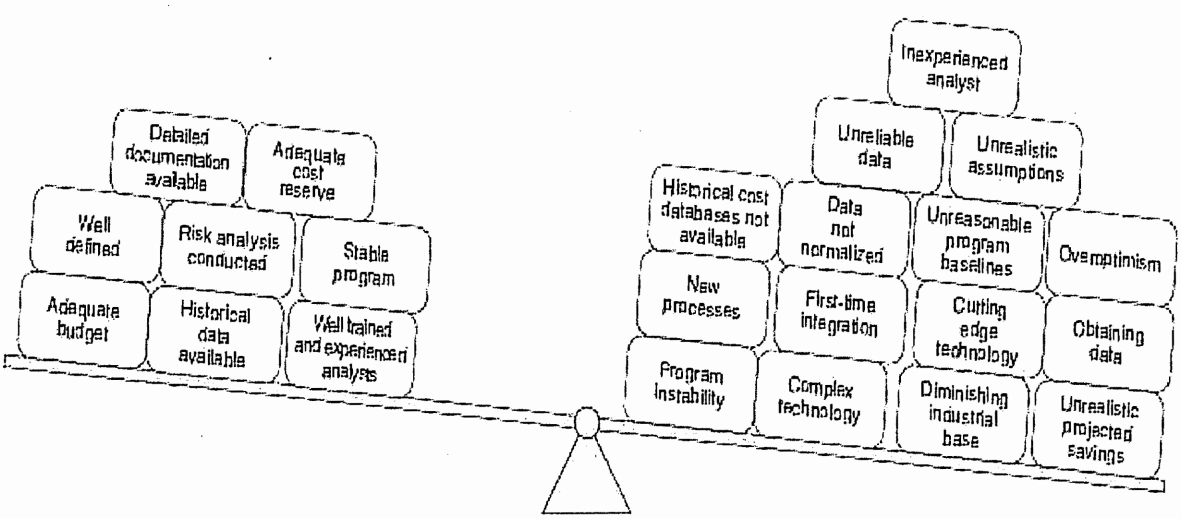


Figure 3.23: Challenges to cost estimators (GOA, 2007).

The deterministic nature of most cost models may lead to a belief that the model output is the only correct solution. However deterministic models always have uncertainties and ignoring this naked fact is a serious analysis error.

3.3. Related Work

Cost modelling has been widely researched producing a plethora of estimation tools that are meant to accurately approximate the overall costs be it for infrastructure deployment or operational costs. In this section we discuss a number of other works that have been done and gave us some insights in the direction of our work.

Wan and Peha (1997) researched on a model to estimate costs based on demand for communication infrastructure. Their focus was two pronged; the cost of adding new equipment to cater for new features on an existing infrastructure and the cost of upgrading the whole network as part of basic service at low cost (Wan, 1997). In this work two functions for cost parameters are distinguished; the demand function and the diffusion function. The demand function $D(\Phi,t)$ represent the potential users willing to use the extra additional features of the network and pay at least Φ per unit of time at time t (Wan, 1997). Demand costs can then be analysed by considering the following inequality (Wan, 1997):

$$\frac{\delta D(\Phi,t)}{\partial \Phi} \leq 0 \qquad (3.27)$$

If equation (3.27) is true for any time t, then there is reduced demand for the network's new feature. On the contrary for increased demand for the new feature, the inequality (3.28) has to hold for $\Phi \geq 0$.

$$\frac{\delta D(\Phi,t)}{\partial \Phi} > 0 \qquad (3.28)$$

From the time the user considers adoption of the new network application to the time of actual adoption there is a time lapse. This delay can be represented by a random variable (Wan, 1997) which has a cumulative distribution function of $F(\tau)$ (Wan, 1997). Assuming $X(\Phi, t)$ to be the function representing the number of adopters at time t given the price of Φ then (Wan, 1997):

$$X(\Phi,t) = \int_{-\infty}^{t} \frac{\delta D(\Phi,\mu)}{\delta \mu} F(t-\mu)d\mu \qquad (3.29)$$

Considering equation (3.29) it is assumed that this is the number of adopters of the new network feature during the period $[\mu, \mu+d\mu]$ (Wan, 1997). Once the number of adopters has been determined the cost C(t), of upgrading the infrastructure is then defined as the function of the upgrade time. The estimation of C(t) is done using the method of scales described in section (3.2.5.1.2.3). If equation (3.30) is valid then the model is assumed to be able to sustain increase in revenue and implementation is considered feasible.

$$\frac{dC(t)}{dt} \leq 0 \qquad (3.30)$$

As it can be observed this model is dependant on technology adoption, a situation which is very common in developed countries. In developing countries this approach is not feasible especially in rural areas where there has to be network deployment first and then demand is later aggregated. Beside Wan and Peha (1997) did not principally focus on the infrastructure (for upgrade) cost estimation methodology, instead their work focused on adoption of additional features on an existing communication infrastructure through upgrades. The level of adoption in conjunction with the estimated cost of upgrade is then set to show revenue monotonicity i.e. increase or decrease. Our approach focuses on deployment of the network infrastructure to poorly serviced areas and eventually aggregate demand.

Another interesting work was done by Valpola and Karhunen (2002) who proposed a cost estimation method known as the Bayesian ensemble learning method for nonlinear dynamic state models. The method combined neural networks and Bayesian probability theory. The ensemble learning provides a good approach to estimation of nonlinear models. They used an ANN with multiple layer perceptron (MLP). In their design the authors had observed data, latent variables of the model and model parameters. They denoted observed data by X = $\{x(t)|t\}$, the latent variables were denoted by S = $\{s(t)|t\}$ and the model parameters by $\theta = (\theta_i)$. An approximation is made for the posterior $p(S, \theta|X)$ with $q(S,\theta)$ as an approximation. The approximation $q(S,\theta)$ is a multivariate Gausian that has a diagonal covariance (Valpola, 2002). This approximation minimizes the cost function. The cost function is represented by the following equation (Valpola, 2002):

$$C = \left\langle \log \frac{q(S,\theta)}{p(S,\theta,X)} \right\rangle = d\big(q(S,\theta)||P(S,\theta|X)\big) - \log p(X) \qquad (3.31)$$

Where $\log \frac{q(S,\theta)}{p(S,\theta,X)}$ represents the expectancy of $q(S,\theta)$.

$D(q||p)$ represents Kullback-Leibler's divergence[5] of q from p.

---

[5] "The Kullback-Leibler (KL) divergence is a fundamental equation of information theory that quantifies the proximity of two probability distributions" (Shlens, 2007:1).

In their work the authors go further to assume a Gausian noise model and represent C_x a likelihood term of C, by the following equation (Valpola, 2002):

$$C_x = \langle -\log p(X|S,\theta)\rangle = \sum_t \langle -\log N(x(t); f(s(t),\theta_f), \textstyle\sum_x)\rangle \qquad (3.32)$$

As it can be deduced from equation (3.32) the likelihood term C_x is dependent upon the first and second moments of $f(s(t), \theta_f)$ over the posterior approximation $q(S, \theta)$ (Valpola, 2002). Suppose that the functions of the multiple layer perceptron are linear the task towards estimating the minimum cost function will be to evaluate the output mean and variance which can easily be done using the mean and variance of the inputs $S(t)$ and θ_f (Valpola, 2002). Since the network cost parameters are non linear there is need to linearize them about the input mean using derivatives (Lappalainen, 2000). Finding the derivative with respect to $S(t)$ gives the following (Valpola, 2002):

$$\frac{\partial f(s(t), \theta_f)}{\partial s(t)} = B\, diag(\theta'(y(t)))\, A \qquad (3.33)$$

Where $diag(\theta'(y(t)))$ denotes the diagonal matrix on the main diagonal

$y(t) = As(t) + a$.

A and B are matrices and,

a denotes a constant.

The derivative is then assumed to be the least cost function variance. In short in this approach the minimum cost function variance is estimated by using derivatives.

We however realize that their approach to model costs can still lead to serious underestimation as the minimum variance can just be a local minima and not a global one. The approach we have used in our cost model ensures that the cost function is global.

Neurofuzzy has also been used for predicting costs of projects. Boussabaine and Elhag developed a neurofuzzy model for predicting costs and duration of construction projects (Boussabaine, 1997). External effects on costs and duration of projects were acted upon by fuzzy functions. This gave outputs which were then defuzzified to produce a set of numbers known as a crisp set (Boussabaine, 1997). We have previously discussed about fuzzy sets and crisp sets (ordinary sets). After defuzzification the crisp set was then used as an input for the NN which underwent training. The NN then produced as output project cost estimates and the estimated duration of the project. However the neurofuzzy model does not include contingency costs during project implementation. Our model addresses this problem as we believe that random cost changes are more realistic in cost models because of environmental and economical factors during project implementation.

As part of his dissertation Valerdi (2005) presented the constructive systems engineering cost model (COSYSMO). COSYSMO was actually a refinement of two earlier versions that had a number of short comings. COSYSMO computes cost estimates of systems engineering effort for hardware and software systems. Its operational concept is represented in Figure 3.24. The size of cost drivers include volatility factor that accounts for the amount of change that is involved, for example it can be used to adjust the number of cost drivers if some were initially omitted. The group of cost drivers of COSYSMO also include what is known as a schedule driver that accounts for expansion that might occur in a project.

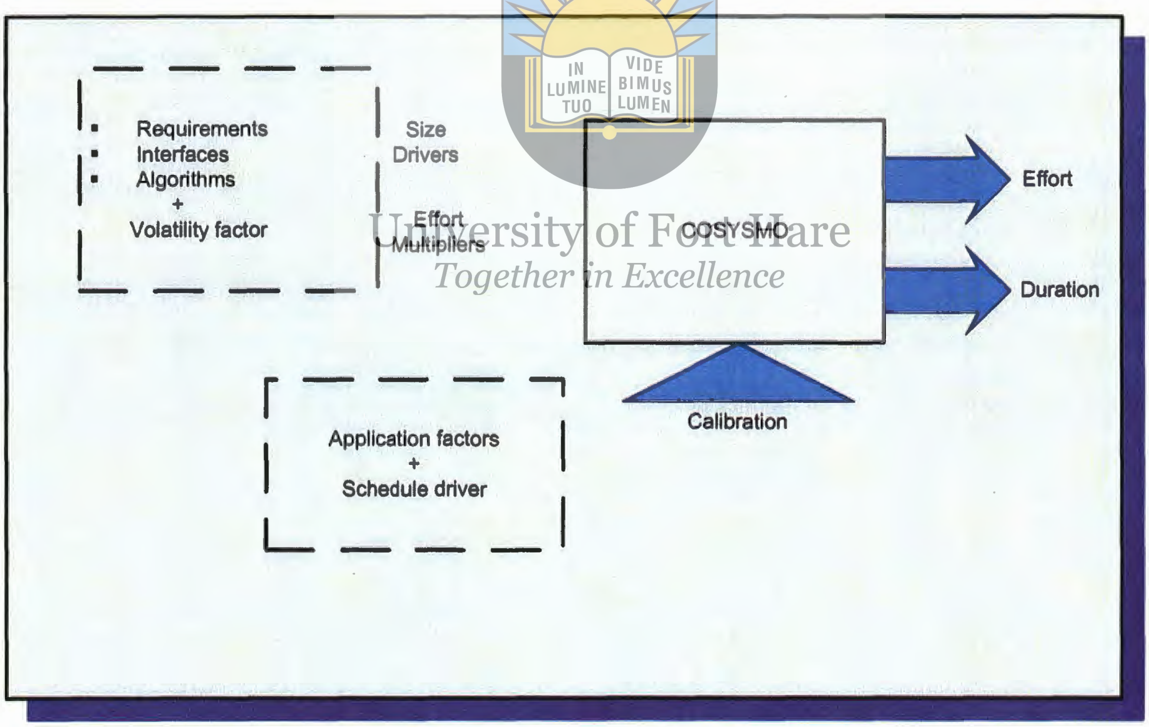


Figure 3.24: COSYSMO operational concept (Adapted from Valerdi, 2005)

To estimate costs Valerdi (2005) employs an algorithm which consists of cost estimation relationships. The complete algorithm is found in (Valerdi, 2005: 30-38). There are two important parts that make up the CER equations; the size factor which represents the additive part and the effort multiplier which represents the multiplicative part (Valerdi, 2005).

However the COSYSMO lacks generality, most of its CERs are designed to estimate the number of "person months" as a function of the size of a project. This makes it more suitable for software development where the principal cost driver is the person months. The selection of the volatility factor is subjective since it depends on the expert's opinion. As we have repeatedly put it, subjectivity introduces an uncertainty which is an unpalatable situation in cost estimation. Therefore COSYMO's application is limited to determining the effort to develop a software project not the costs of the project. In contrast our approach is general, factoring in all cost drivers that are influential in network deployment.

Iranmanesh and Zarezadeh (Iranmanesh, 2008) used an ANN to forecast actual cost of a project to improve Earned Value Management System (EVMS). In their work various cost components were mapped by a training function to give an S-curve (Figure 3.25). Figure 3.25 shows various cost components; Actual Cost of Work Performed (ACWP), Budgeted Cost of Work Scheduled (BCWS), Budgeted Cost of Work Performed (BCWP), Budget at Completion (BAC).

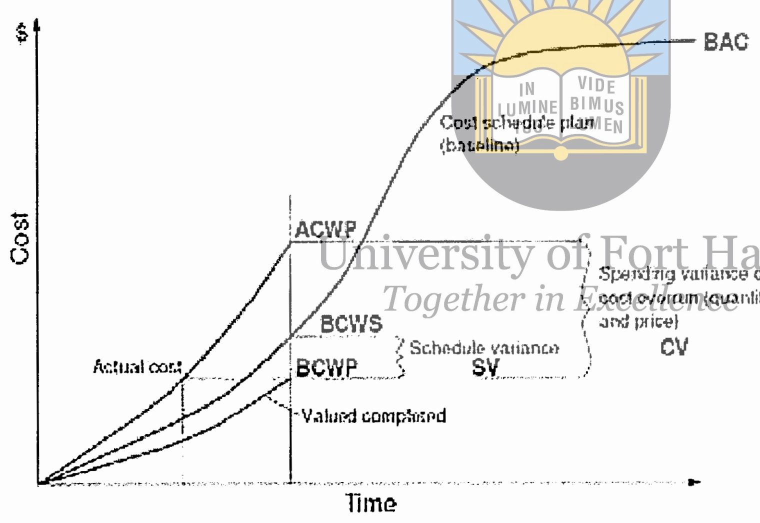


Figure 3.25: Basic time and cost S-curve in EVMS (Iranmanesh, 2008)

The authors then computed the mean absolute percentage error (MAPE). The equation for MAPE can be found in (Iranmanesh, 2008: 242). On applying the ANN, back propagation was used as a learning algorithm on multiple layer perceptron (MLP) architecture; Figure 3.26 shows the MLP used by the authors.

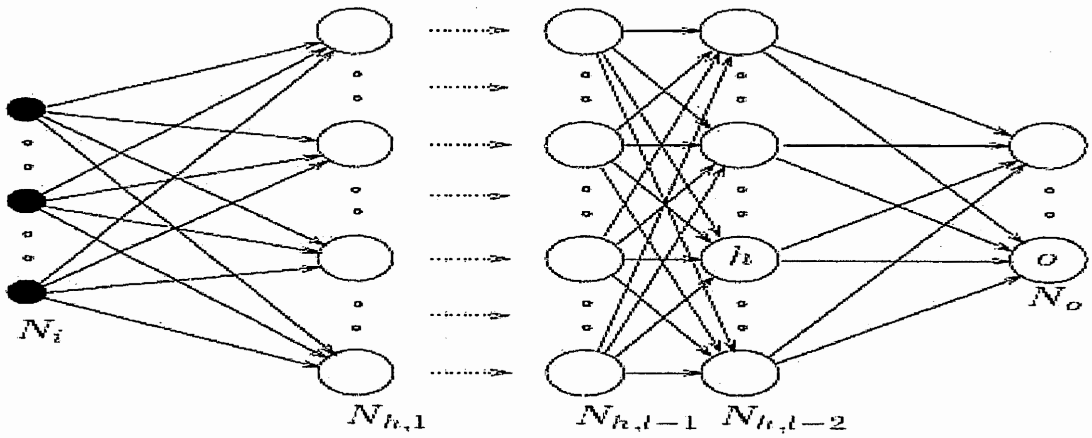


Figure 3.26: Multiple layer perceptron (Iranmanesh, 2008)

They then considered 5 different types of NN, with 2, 3, 7 and 10 neurons in a hidden layer. Table 3.2 shows the calculated MAPE for the different type of NN. The idea was then used to select the MAPE with the smallest value as this is believed to be as close as possible to the actual costs.

Table 3.2: MAPE for different type of NN structure (Iranmanesh, 2008)

Number of neurons in hidden layer	2	3	5	7	10
MAPE	5.2485	4.5378	3.8632	4.0724	5.3650

Its corresponding NN was then trained and used in the forecast of EAC in two projects that the authors randomly selected. Their findings represented in figure 3.27 (a) and (b), revealed that there was strong relation between forecasted and actual costs. In those two figures the "continuous line represents the real values of ACWP for five periods of time" (Iranmanesh, 2008: 243) for both projects and the dashed line are forecasted values. Consequently ANN appeared to be giving a close estimate of the actual costs. In figures 3.27 (a) and (b) the values on the x-axis are the 5 periods of time during the investigation. The selected periods were 20%, 40%, 60%, 80% and 100% of the project duration (Iranmanesh, 2008). These percentages are represented as 1, 2, 3, 4, and 5 respectively on the x-axis.

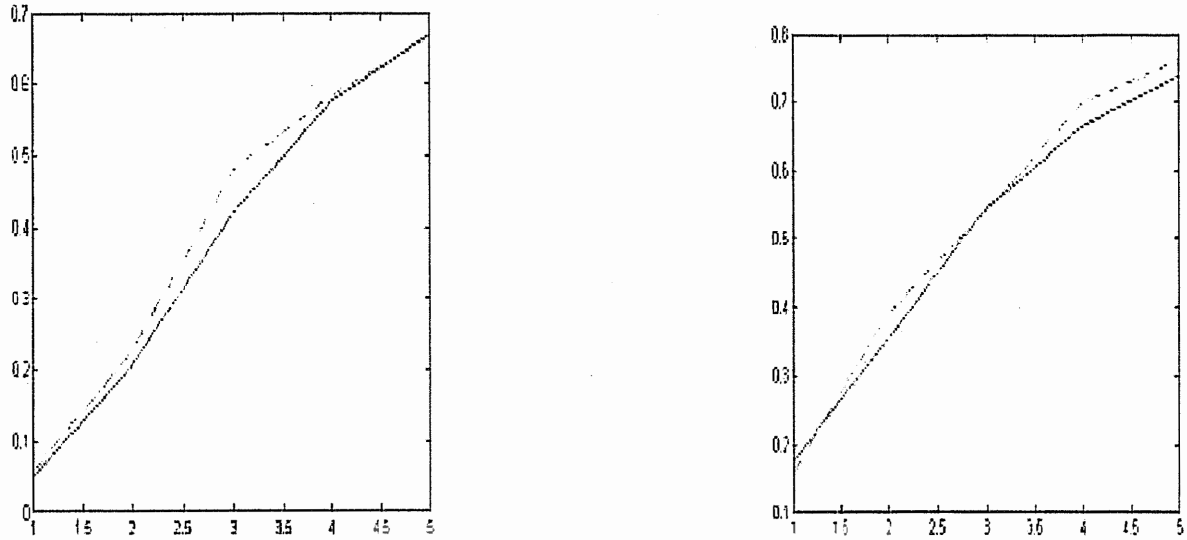


Figure 3.27: (a) Results for project 1 (b) Results for project 2 (Iranmanesh, 2008)

While the authors' approach to cost estimation is very commendable it has problems inherent from the use of the ANN. One of them is that it is applicable to big projects where there are large data sets that are needed for the training of the NN. The model does not provide for sensitivity analysis of the relationships between inputs and outputs in contrast to our approach that addresses these limitations.

Previous costs models based on statistical measures include work by Anandkumar A (2008). In his work the author considered the problem of minimum cost in-network fusion of measurements, collected from distributed sensors via multihop routing. He then extended to finding a fusion scheme that achieves optimal trade-off between the total routing costs and the resulting end inference performance at the fusion centre. Statistical modelling techniques have also been used to enrich interactive sensor querying by Deshpan A et al (2004). The authors demonstrated that such models can help provide answers that are both more meaningful, and, by introducing approximations with probabilistic confidences, significantly more efficient to compute in both time and energy. However we must emphasize that there is still little literature on rural cost models of wireless networks.

3.4 Conclusions

In this chapter we reviewed cost models carefully focusing on their data levels and the cost modelling cycle. Costs can be grouped into economic (costs for adding new services or a new technology) and accounting costs (historical costs); their compositions have also been discussed in this chapter. Cost estimation is part of project cost management process that also includes resource planning, budgeting and cost control. We have noticed that cost estimation plays a central role in cost modelling hence selection of the cost estimation method should be carefully done considering its merits and de-merits under different environments.

A number of methods are available for selection, these were categorised under non-algorithmic and algorithmic estimation methods. Non-algorithmic methods we discussed include; expert judgement which depends strongly on the experience of the expert and is very subjective, Analogy method whose limitations include not being able to handle categorical data, fuzzy Analogy which is an improvement on Analogy being able to handle categorical data and finally Artificial Neural Network method. The algorithmic methods were found to be those that make use of mathematical formulae and predetermined steps to arrive to an estimate. Under this category we discussed; the Mean Least Square Regression, the method of scales which varies the cost estimate according to size making use of a scaling factor, parametric methods, engineering estimation, and capacity factored estimation method. Cost estimation is an alternative to traditional methods that are based on actual costs of individual components. In this chapter we have also attempted to identify the benefits of cost estimation to justify this method's precedence over the traditional ones. Having considered all the cost estimation techniques and their short comings our cost model utilises the Poisson process to address those limitations as we discussed in this chapter. The next chapter therefore discusses the underlying theory of the Poisson process and the statistical analysis in cost models which is the measure of success against which we test the validity of the DACM.

CHAPTER FOUR

STATISTICAL ANALYSIS AND THE POISSON PROCESS IN MODELLING COSTS

4.0 Introduction

The incorporation of statistical analysis in cost modelling has immense benefits and any model that is constructed outside its influence is void of credibility. When a cost model is constructed there are a number of cost outliers[6] because of randomness of cost parameters and contingency costs. Outliers are observations that are numerically distant from the whole set of data. Their presence may be the outcome of sampling errors. Statistical analysis is needed to cope with any undetected outliers as these may seriously distort cost estimates and produce misleading results. This chapter presents a discussion on statistical analysis and its influence on modelling costs. During project deployment many cost changes take place and these require immediate adjustments in order to control the deployment costs. These changes occur randomly and can be modelled with the Poisson process as their occurrences tend to follow the Poisson distribution. The Poisson process concept is therefore presented in this chapter, exploring sufficient conditions for the Poisson distribution.

4.1 Statistical Analysis

Statistical analysis plays an important part in deriving from some observations of a random process, the attributes and behaviour of the process entities (Casella and Berger, 2001; Yun, 2005). Statistical analysis is two fold consisting of model construction and the performance of sensitive analysis to model the future of a similar process. This process is inductive in nature (Yun, 2005) as it provides a finer-grained quantitative range of evaluation standards both on the constructed cost model and the dynamic interaction of its components. The resultant evaluations of the cost model and its components can then be generalised with substantial evidence extracted by the induction process. Figure 4.1 shows the process of statistical analysis. The diagram illustrates that the model is populated with parameters which are used to design the experiment. Some statistical inferences about the model are produced from the sample statistics. The quality of inference depends on how the population parameters are used to design the experiment.

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[6] Cost outliers are costs that deviate remarkable from the mean , they are indicative of the total cost estimate error

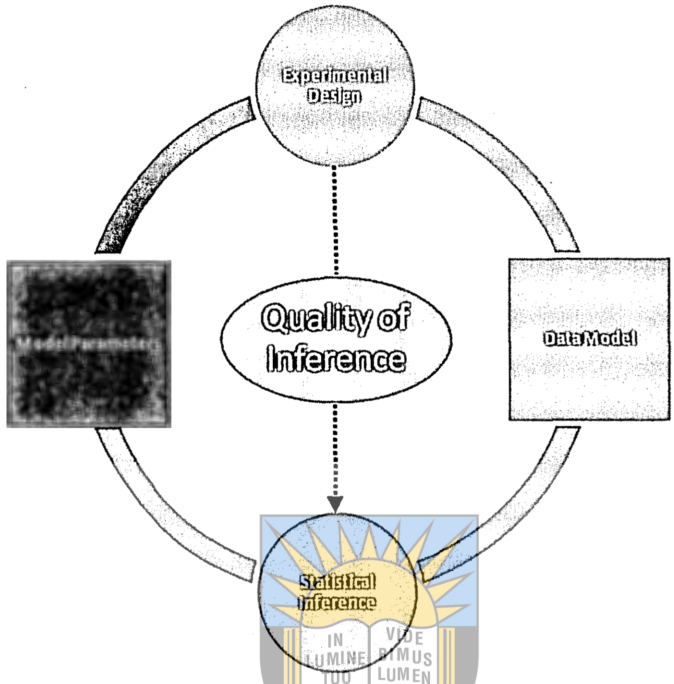

Figure 4.1: Statistical Analysis (adapted from Yun, 2005)

There are two approaches to statistical analysis namely the nonparametric and parametric (Yun, 2005). The nonparametric approach uses all the complexities of a phenomenon from recorded data to try and minimize assumptions (Yun, 2005). This approach does not rely on the estimation of parameters. Examples of nonparametric methods include the Kolmogorov-Smirnov test (Schindler M., 2008) for comparing for instance the mean of two different cost models, Sign test[7] and Wilcoxon's[8] matched pairs test for comparing two variables in the same cost model and the coefficient Gamma for expressing variable relationships.

Parametric approach makes a representation of observed data using a distribution function $y = e^{-\alpha}$ in the case of a Poisson distribution, these (the functions) vary according to the type of the distribution. Statistical analysis enables the retrieval of causes from effects or vice versa. The retrieved knowledge can then be used to improve future predictions about certain parameters. Statistical analysis is also vital towards supporting conclusions on the optimality of predictions through various models.

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[7] *The sign test is used to test the null hypothesis that the median of a distribution is equal to some value. Note that the Wilcoxon Signed Rank Sum Test is also appropriate in these situations and is a more powerful test than the sign test.*

[8] *Wilcoxon signed-ranks test applies to two-sample designs involving repeated measures, matched pairs.*

4.1.1 The Role of Statistical Analysis in Cost Modeling

Statistical methods are an integral part of modelling any real world phenomenon. Their power is realized where robust conclusions are to be made following a cause and effect investigation. They are made use of to test hypothesis and explore data sets to unearth a number of findings relating to cost parameters and their influences on various components of the model. Statistical analysis also plays a big role in extracting maximum information from the explored data sets (Diggle et al, 2002). One of the objectives of cost modelling is to make inferences about various parameters. The achievement of this objective on its own does not enable us to make sound conclusions. Sound conclusions can only be made after statistical methods have indicated how reliable inferences of the model are. They also give guidance when building cost models by determining the format of the data and the sampling methods.

4.1.2 Confidence Intervals

We indicated in Chapter 3 that cost models, besides showing the interaction of parameters, they are also used to forecast the future (Box et al, 1994). Since forecasting make use of historical data there is always a degree of uncertainty associated with the results. To accept those results as being representative of the real phenomenon the degree of uncertainty has to fall within a determined confidence interval. The confidence interval indicates how strong or weak should we consider the conclusions arrived at through statistical analyses and in that way it is possible to quantify the precision of the estimate.

4.2 The Poisson Process

Within the ordinary logic most of the arguments are arrived at through the process of deductive reasoning. This reasoning process moves from the general to the specific. One hindrance about this is that we can hardly expand much our knowledge about the model or system under discussion. In this technological age, systems become more and more complex, and to form arguments leading to conclusions which go beyond what is already public domain knowledge, we need to apply tools that are beyond deduction. Such tools operate on some observed events occurring at certain intervals of time and also on some particular set of observations and make a number of tentative changes to arrive at different conclusions for different changes made.

Most real world problems often require a stochastic model that captures the main characteristics of the problem and serves as a tool to compute diverse quantities of interest (Randolph and Sahinoglu, 1995). Examples include modelling the network down time and the determination of cost changes during network deployment. This involves an analysis of occurrences which are randomly distributed over certain intervals using the Poisson process. To discuss about the Poisson process we first need to understand what a stochastic process is.

4.2.1 Definition of a Stochastic Process.

A stochastic process which is denoted by X(t), such that $t \in T$, consists of random variables X(t). The parameter t is the time included in the time universe T. All possible values of X(t) form what is known as the state space of the stochastic process. Within the state space each possible value is therefore referred to as the state of the process. There are two directions that X(t) can take, if the universe T is countable, then X(t) is a discrete process and if the universe T is a continuum, then X(t) is a continuous stochastic process.

The stochastic processes can be distinguished by (Randolph and Sahinoglu, 1995):

- their universe set T,
- their state space or
- the interdependencies of the random variables X(t).

The Poisson process which is discussed in Section 4.2 is a stochastic process. It is the process X(t) that has:

- Stationary independent increments,
- Discontinuous sample paths and
- A Poisson distribution.

A consideration is made that the discrete variable X(t) is the total number of occurrences in the time interval [0, t]. A Poisson process can help in studying a phenomenon with observable behaviour in order to extract certain characteristics that are not obvious to the naked eye. An example in cost modelling is the determination of cost changes that occur within a certain period in order to estimate the total costs, say for network deployment.

4.2.2 Conditions for a Poisson Model

For a Poisson model the following conditions have to be satisfied (Brown et al, 2001):

- Events occur singly and at random in a given interval of time or space, Figure 4.2 illustrates the independent arrival of events
- λ, the mean number of occurrences in the given interval, is known and finite.

If for a given interval there are X occurrences of events (i.e. X can denote the number of incidents causing cost change during project deployment) then the variable X is said to follow a Poisson distribution (Brown et al, 2001) which is written as:

$$X \sim P(\lambda),$$

where:

$$P(X = x) = e^{-\lambda}\frac{\lambda^x}{x!}, \qquad for\ x = 0, 1, 2, \ldots to\ infinity \qquad (4.1)$$

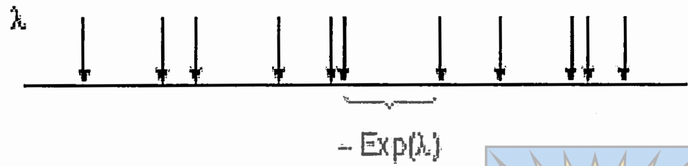


Figure 4.2: Independent arrival of events (Vitamo, 2003)

4.2.3 Mean and Variance of the Poisson Distribution

The mean number of occurrences in the interval λ, is all that is needed to define the distribution completely; λ is the only parameter of the distribution. In a Poisson distribution, it is clear that the mean *(E(X))* is equal to λ, but also the variance *(Var(X))* is also equal to λ. This brings us to the conclusion that if $X \sim P(\lambda)$, then:

$$E(X) = \lambda \qquad (4.2)$$

and also

$$Var(X) = \lambda \qquad (4.3)$$

The application of the concept of the Poisson process in cost modelling is born out of the realization that the probability of an event (e.g. cost change) in one interval is independent of the probability of an event in any other interval that is not overlapping with the first. The key point is to compute the probability density function (p.d.f) of the total cost of change. Poisson p.d.f. may be used in a number of economic models. The number of cost adjustments on a project over time models a Poisson process. Let *C(x, t)* denote the probability x cost changes in each interval of length t. Let *O(h)* represent any function such that

$$\lim_{h \to \infty} \frac{O(h)}{h} = 0 \qquad (4.4)$$

The Poisson process states that:

a)

$$C(1,h) = \lambda h + O(h) \qquad (4.5)$$

b)

$$\sum_{x=2}^{\infty} C(x,h) = O(h) \qquad (4.6)$$

c) The numbers of cost changes in non overlapping intervals are stochastically independent.

Part a) and c) lead to the conclusion that the probability of one cost change in a short interval h is independent of changes in other non overlapping intervals and is approximately proportional to the length of the interval. The substance of b) is that the probability of two or more changes in the same short interval h is essentially equal to zero. If $x = 0$, we take $C(0,0) = 1$. In accordance with a) and b), the probability of at least one change in an interval length h is $\lambda h + O(h) + O(h) = \lambda h + O(h)$. Hence the probability of zero changes in this interval of length h is $1 - \lambda h - O(h)$. Thus the probability $C(0,t+h)$ of zero changes in an interval of length x+h is in accordance with c), equal to the product of the probability $C(0,t)$ of zero changes in an interval of length t and the probability $1 - \lambda h - O(h)$ of zero changes in a non overlapping interval of length h.

That is:

$$C(0,t+h) = C(0,t)(1 - \lambda h - O(h) \qquad (4.7)$$

Then

$$\frac{C(0,t+h) - C(0,t)}{h} = -\lambda C(0,t) - \frac{O(h).C(0,t)}{h} \qquad (4.8)$$

If we take the limit as $h \rightarrow 0$, we have

$$D_t(C(0,t)) = -\lambda C(0,t) \qquad (4.9)$$

This is a differential equation whose solution is:

$$C(0,t) = me^{-\lambda t} \qquad (4.10)$$

Where m is a constant.

The condition $C(0,0) = 1$ implies that $m = 1$,

Then

$$C(0,t) = e^{-\lambda t} \qquad (4.11)$$

If x is a positive integer, we take $C(x, 0) = 0$. This implies that:

$$C(x,t+h) = [C(x,t)][1-\lambda h - o(h) + [C(x-1,t)][\lambda h + o(h)] + o(h) \qquad (4.12)$$

Accordingly we have:

$$\frac{C(x,t+h) - C(x,t)}{h} = -\lambda C(x,t) + \lambda C(x-1,t) + \frac{o(h)}{h} \qquad (4.13)$$

And

$$D_t\,[C(x,t)] = -\lambda C(x,t) + \lambda C(x-1,t) \qquad (4.14)$$

For $x=1, 2, 3 \ldots$.

It can be shown by mathematical induction, that the solutions to these differential equations, with boundary conditions $C(x, 0) = 0$, for $x=1,2,3 \ldots$, are, respectively

$$C(x,t) = \frac{(\lambda t)^x}{x!} e^{-\lambda t} \qquad (4.15)$$

Hence the number of changes X in an interval of length t has a Poisson distribution with parameter:

$$m = \lambda t \qquad (4.16)$$

The moment generating function of a Poisson distribution is given by:

$$M(t) = \sum_x^{\infty} e^{tx} f(x) = \sum_{x=0}^{\infty} e^{tx} \cdot \frac{m^x e^{-m}}{x!} \qquad (4.17)$$

$$= e^{-m} \sum_{x=0}^{\infty} \frac{(me^t)^x}{x!}$$

$$= e^{-m} e^{me^t} = e^{m(e^t - 1)}$$

for all real values of t. Since:

$$M'(t) = e^{m(e^t-1)}(me^t) \qquad (4.18)$$

And

$$M'' = e^{m(e^t-1)}(me^t) + e^{m(e^t-1)}(me^t)^2 \quad (4.19)$$

Then

$$\lambda = M'(0) = m \quad (4.20)$$

And

$$\sigma^2 = M''(0) - \mu^2 = m + m^2 - m^2 = m \quad (4.21)$$

That is, a Poisson distribution has

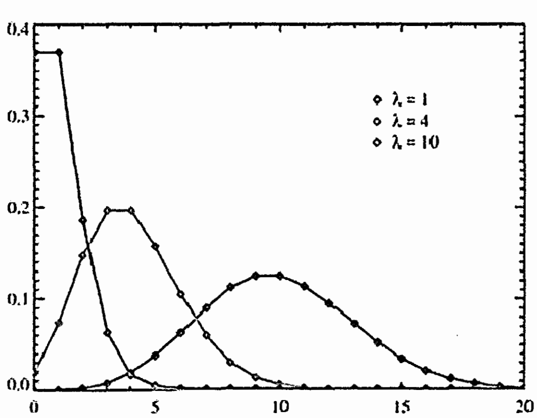
$$\lambda = \sigma^2 = m > 0 \quad (4.22)$$

Thus the parameter m in a Poisson p.d.f. is the mean μ.

The Poisson p.d.f. is frequently written as:

$$f(x) = \begin{cases} \dfrac{\lambda^x e^{-\lambda}}{x!}, & x = 0,1,2\ldots \\ 0, & else\ where \end{cases} \quad (4.23)$$

The Poisson probability density function is diagrammatically shown in Figure 4.3. The values of λ were just chosen to illustrate the behaviour of the function when the mean is varied. When the mean becomes larger the function approaches the normal distribution (i.e. λ=10). Figure 4.4 shows the cumulative distribution of the p.d.f.



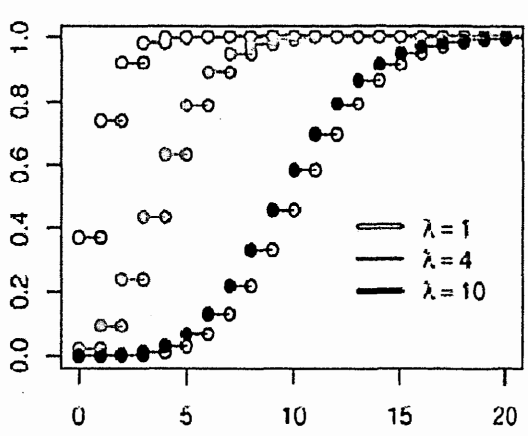


Figure 4.3: Poisson p.d.f Figure 4.4: Cumulative distribution functions (both Adapted from Wikipedia/Eco, 2008)

4.2.4 Modeling Cost Changes with the Poisson Process

During the time when network infrastructure is being deployed there are various changes in costs that may take place. These may emanate from labour costs adjustments, underestimation of total costs during the initial stages, or as a result of inflation. To understand cost changes we need to understand the probability behaviour and meaning of the increment $X(t_1+t_2) - X(t_1)$ from time t_1 to time t_1+t_2, where $t_2 > 0$ and $t_1 \geq 0$. Further more it can be noticed that $X(t_1)$ is itself an increment that is from time 0 to time t_1 which can be written as $X(t_1) - X(0)$. Let $X(t)$ be a counting random process indicating the number of cost changes that can take place within a certain interval. Then the important property of the Poisson process that can be applied is that the increments of the number of cost changes on none overlapping intervals of time are independent of each other. The implication of this is that knowing the number of cost changes in one interval of time does not in anyway indicate any information about the number of cost changes in another interval. This can be represented using probabilities

Let $\lambda(t)$ be the intensity of cost changes, C be a cost change that occurred in the interval [t, t + dt] and Q any information about the cost changes then:

$$P(C|Q,\lambda,M) = P(C|\lambda,M) = \lambda(t)dt \qquad (4.24)$$

Accordingly the probability of finding a cost change in an interval [t, t + dt] is proportional to the size of that interval:

$$P(C|\lambda,M) = \lambda(t)dt \qquad (4.25)$$

What we can notice in different intervals is the rate (intensity) at which cost changes are occurring on average. Evaluating the intensity function λ at time t gives us the intensity as $\lambda(t)$. Furthermore the Poisson process X which has an intensity function λ has the following attributes:

- X is a counting process where $X(0) = 0$ and for $t > 0$ $X(t)$ is non decreasing and only takes positive integers
- If the intensity function λ is a constant, then X is known as a homogeneous Poisson process
- X has independent increments

4.2.5 Emerging Poisson Processes from Existing Ones

There are situations that arise in applications and result in creating new Poisson processes from existing ones. In this regard this section discusses the counting special types of events and the sums of Poisson process. Our discussion here is brief however more detailed explanations can be found in specialized literature like (Dey and Rao, 2005:17-90; Bernardo et al, 1999:849-858; Moller and Waagepetersen, 2004).

4.2.5.1 Counting Special Types of Events

We may be interested in counting various special types of the events being counted by a Poisson process for example if we are counting the number of cost changes as our basic events, we might be interested in counting those with magnitude more than R 10 000 but less that R 15 000 and those greater than R 15 000. If in a certain month cost changes occur at the Poisson intensity of 10 per month and the probability of a cost change exceeding R 15 000 is 0.2, so effectively 20% of the cost changes exceed R 15 000. Then the intensity of cost change per month will be $0.2 \times 10 = 2$.

4.2.5.2 Sums of Poisson Process

Suppose that the Poisson processes X_1 and X_2 with intensities of λ_1 and λ_2 are independent. Then X defined by $X(t) = X_1(t) + X_2(t)$ is a Poisson process with intensity function λ given by $\lambda(t) = \lambda_1(t) + \lambda_2(t)$.

4.2.5.3 Compound Poisson Process

The concern when estimating costs of project deployment squarely rests on the frequency of cost changes within an interval. Another concern is about the aggregate cost change, this is the sum of all cost changes. Also of great concern is the size of each cost change. If the sizes of cost changes are independent from each other, the random process is called a compound Poisson process.

4.2.6 Poisson Noise and Characterization of Small Occurrences

The total number of cost changes during the whole period of interest has a mean λ (Wikipedia/Eco, 2008) and since the variance is also equal to the mean for a Poisson distribution its standard deviation is:

$$\sigma = \sqrt{\lambda} \qquad (4.26)$$

In other words the occurrences of cost changes tend to fluctuate about the mean of their distribution with a standard deviation of σ (Wikipedia/Eco, 2008). These fluctuations are known as the "Poisson noise" (Wikipedia/Eco, 2008: no page numbers). The fluctuations can be used to estimate the effect of one cost change to the whole summation of the cost changes.

4.3 Conclusions

In this chapter we have discussed the influence of statistical analysis in building cost models. We further discussed the Poisson process as it is central to our cost model. We first presented the conditions that are necessary for the Poisson distribution and showed how the Poisson process can effectively deal with the randomness of cost changes during the project deployment. The necessary conditions are; that the events causing cost changes to network deployment occur singly and at random in a given interval of time or space and that the mean number of occurrences in the given interval, is known and finite. More important to the Poisson process are the mean and variance of the distribution hence this chapter also presented a discussion on them. They are important because they are the only parameters of a Poisson distribution and they are equal. The underlying theory of the Poisson process lays a foundation for the construction of our cost model hence the following discussion centres on the reference models for the DACM and the process of applying the Poisson process to estimate the wireless network deployment contingency costs.

CHAPTER FIVE

THE WIRELESS NETWORK DEPLOYMENT FRAMEWORK

5.1 Introduction

As one of the important steps towards our model specification this section presents the model's architecture and its references. These two terms are sometimes used interchangeably by many researchers. They are however different in their strict meanings. The model architecture represents a section of the entity relationship while the reference model is the summation of different architectures. Reference models form the conceptual basis for the development of a more concrete model and ultimately implementation in a computing environment. The development of model architecture and its reference guarantees that the model has all information and requirements systematically documented. In this chapter we discuss reference models that are central to the wireless cost model. These reference models show the cost areas that are the basis of deriving our model parameters. The chapter also details the derivation of the equations used in the model to estimate the contingency costs. It is important to support a claim that the occurrence of incidents causing cost changes can be modelled with a Poisson distribution. In the chapter we make use of graphical illustrations to support the assertion that the incidents causing cost changes in the wireless network deployments fit the Poisson distribution.

5.2 The Wireless Network Reference Models

5.2.1 The Planning and Design Reference Model

In this section we discuss the components of planning and design costs, these are shown in figure 5.1. We outline how those costs arise and consequently affect the total deployment costs.

5.2.1.1 Infrastructure Design and RF Design Costs

Very important is the design of the system which has a big impact on the overall cost of the system. The processes that are involved here include diagrams that indicate the interconnection of related software and hardware components. The costs of the equipment necessary for wireless network deployment are also considered during design.

Design and planning are very fundamental phases of network deployment (Egea-Lopez et al, 2005). These phases may however turn to be the most difficult processes in network deployment. Poor design may lead to unprecedented increase of deployment costs (Mallick M, 2003) in an effort to address the resultant loop holes. The main purpose of planning is to guide the whole deployment process and design aims at reducing or elimination problems of interference (RF) while delivering high throughput. This certainly makes the network very reliable and considerably secure. Perhaps let us show what is involved in network design which justifies incurring design costs. Designing a network needs defining tasks and requirements. These tasks may include possible number of users, physical location as well as security issues. Also entailed is the technical element specifications that include APs, types of antennas, wireless router e.t.c. Central to network design is the network stack (Arampatzis et al, 2005; Pathak and Prasann, 2006) whose responsibility is to form the network and maintain it. The stack design should cope with the changes in the quality of the wireless links between nodes. Where signal interference reaches high levels, the network stack should be able to reroute signals to communication routes that are free from interference. This improves efficient transmission of signals from source nodes to destination nodes (Uysal-Biyikoglu et al, 2002). Another consideration during network design is the latency requirements (Zvanovec, 2003) which include time for transmitting signals. Consequently, network design aims at minimizing the overall network costs while meeting performance optimization. The planning and design costs shown in Figure 5.1, are projections resulting from infrastructure design costs, project management costs, RF design costs as well as consulting and requirements analysis costs.

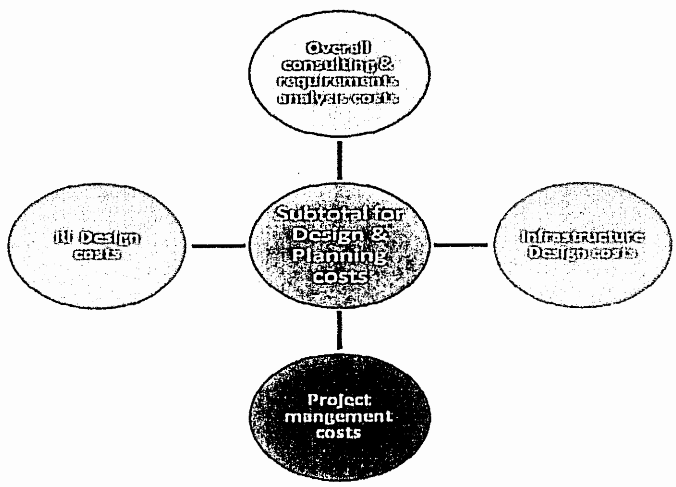


Figure 5.1: Design and Planning Costs

5.2.1.2 Consulting and Requirements Analysis Costs

These are costs that are incurred on consulting services that provide the appropriate expertise required to make the optimum managerial solution for critical needs of the network deployment. The consultants develop the most comprehensive solutions for managing the integration of the network. Their work includes giving strategic recommendations, writing system specifications, assisting with planning and design, checking for technical weaknesses and analyzing critical situations. The consultants perform security tests by doing penetration testing (Housley and Arbaugh, 2003; Tiller, 2005) which helps to identify how intruders can exploit vulnerabilities. At times a network design may result in network leakages (Dyce, 2005) so they identify possible points of leakages.

5.2.1.3 The Project Management Costs

The process of deploying wireless network adheres to the general project management process therefore the costs of project management are an important factor in modelling the costs of wireless deployment.

5.2.2 Network Infrastructure Reference Model

The network infrastructure costs are composed of hardware costs, cabling costs and installation costs as shown in Figure 5.2. These costs come as a result of various activities carried out during deployment; like network installation, cabling, and purchasing hardware.

5.2.2.1 Network Installation Costs

Network installation involves router installations; routers convert signals that are transmitted through the Internet connection into a wireless broadcast (Rappaport, 1996). Other costs are as a result of developing an installation plan, setting up antennas (Liu W.C, 2004, Ammann and Farrell, 2005), installing network interface cards, AP installation and configuration, wireless controller installation and configuration, installation of the wireless management system, performance testing and coordinating the installation in general. Antennas (to a lesser extent in rural environments) and APs play an important role in determining the installation costs. Antennas can be external or internal. External antennas extend the distance of connection. The most popular antennas are directional antennas (Liberti and Rappaport, 1999; Carr, 2001; Ulukan, 2005) that are normally installed at the client side. Examples include the parabolic and the yagi. At the access point the most popular type of antennas are omni-directional or sector antennas. After installation has been completed there is the documentation process. This process involves diagrammatically representing network components such as the location of APs and wireless routers. Documentation is important for trouble shooting and upgrading the network.

5.2.2.2 *Cabling Costs*

When thinking about wireless deployment one is tempted to think none use of cables. This is however not the case, cables are used to connect antennas to the APs. There are two common cables; the thin cable (about 0.1 inch in diameter) and the thicker cable (about 0.4 inch) (Gast, 2006). The thin cable is relatively cheaper in terms of costs than the thicker cable.

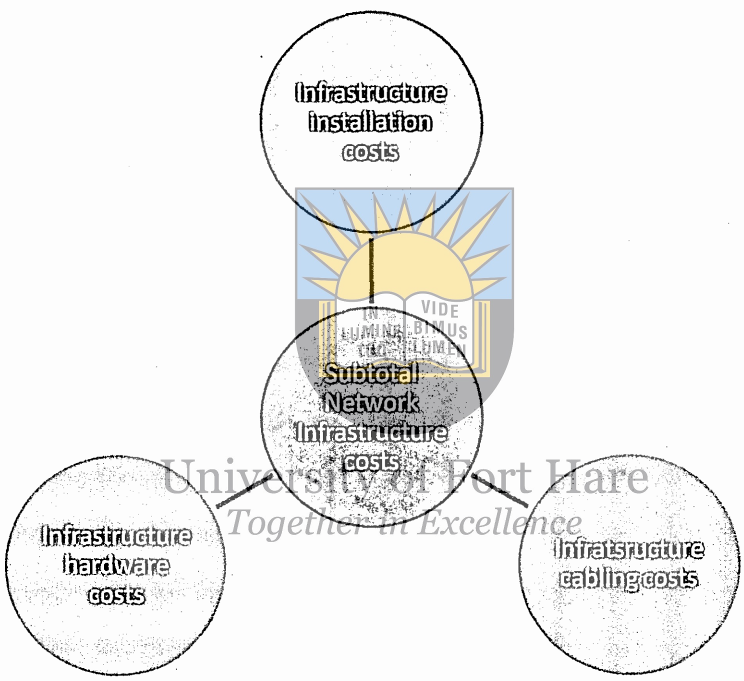


Figure 5.2: The network infrastructure reference model

5.2.3 *The Hardware Costs Reference model*

Wireless hardware includes Access points, antennas, servers, controllers, hubs, switches, adapters and many other types. All wireless network components that connect into a wireless medium are generically called stations. These fall into APs, controllers and clients. For average network coverage APs and controllers significantly influence the total hardware costs. In Figure 5.3 AP costs and controller costs make up our hardware costs reference model.

5.2.3.1 Access Points

APs are an alternative to routers. They serve as a hub for the wireless client and also serve as a bridge to UTP LAN network. Because of this two pronged purpose, APs have UTP port and antenna. The functions of APs may at times be complex such as serving as DHCP server, proxy server as well as firewall. The APs can also embed protection to limit access for certain MAC address. Some APs come with factory default omni directional antennas that cover an area that is roughly circular. For this reason it is very common to place APs in central locations. However desired coverage areas are rarely circular hence locating APs in central positions may not optimize costs and performance. Instead it can necessitate the purchase and deployment of more APs to cover gaps and this increases the total costs for wireless hardware.

Figure 5.3: The wireless hardware reference model

5.2.3.2 Controllers' Costs

A controller is an appliance that is responsible for automatically optimizing the wireless network. It also supports advanced mobility services of the network. In general controllers are responsible for wide range functions like security policies, intrusion prevention and detection, RF management, quality of service (QoS) and mobility. The costs of a controller depend on its functional complexity. An example of a more complex controller is the WC- 3000 all-in –one. This controller is suitable for larger network deployments meant to cover a very big area. It has an inbuilt high power AP with 200 mWatts transmit output, and 4 dBi omni directional antennas, for a total output of 27dBi. The WC-3000 controller (shown in Figure 5.4) can adjust automatically to any subscriber configuration and subscriber access can be authenticated via local user database. Another controller with functional complexities that are responsible for its high costs is the Cisco LAN controller 2106. It has 8 ports and works with Cisco light weight APs. This controller presents the network administrators with visibility and control necessary to effectively and securely manage WLAN and mobility services. However the more functionality a controller has the more costly it becomes.

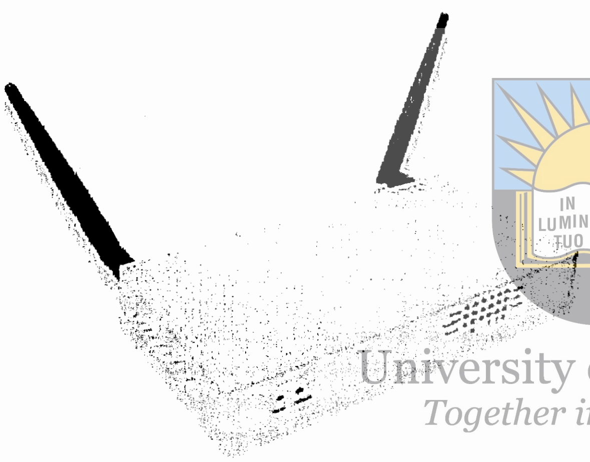


Figure 5.4: WC-3000 Controller (http://products.wi-fiplanet.com/wifi/hotspot_access_controller/1092167282.html)

After installing the equipment testing is done to determine quality assurance of the system. Some kind of back-out procedure is carried out if the deployment's quality assurance is questionable. This involves attending and enhancing those points that can level quality assurance.

5.2.4 The Wireless Installation Costs Reference Model

The component costs represented in Figure 5.5 make up the wireless installation costs reference model. It consists of wireless certification, go live support, and the user training. These components are briefly discussed in the sections that follow.

Figure 5.5: The wireless Installation reference model

5.2.4.1 Wireless Certification Costs

These costs are incurred as a result of giving network support staff training in areas such as network applications, network engineering, and hardware as well as network security.

5.2.4.2 Go Live Support Costs

Go live support is concerned with supporting and optimizing the operative system, technical infrastructure and load distribution as well as the network's business process. The objective is to ensure that the system functions as smoothly as possible. Also included in go live support costs are documentation costs, costs for maintenance contract, and costs of training manuals that can be used to quickly train end users and include customized standard operating procedures.

5.2.4.3 User Training Costs

Properly trained individuals are needed to make networks secure, cost effective and reliable. The objective of user training is to give them skills to implement, support, and optimize wireless networks. The training provides for a strong foundation of basic networking concepts, imparting skills to effectively troubleshoot and secure a TCP/IP network. The training can be through inviting an expert to train the network support staff or by training the in house instructor on the ins and outs of wireless connectivity.

5.2.5 Management and Installation Reference Model

The management installation reference model is composed of the management tool installation, wireless integration and infrastructure installation training. Figure 5.6 shows the management and installation reference model.

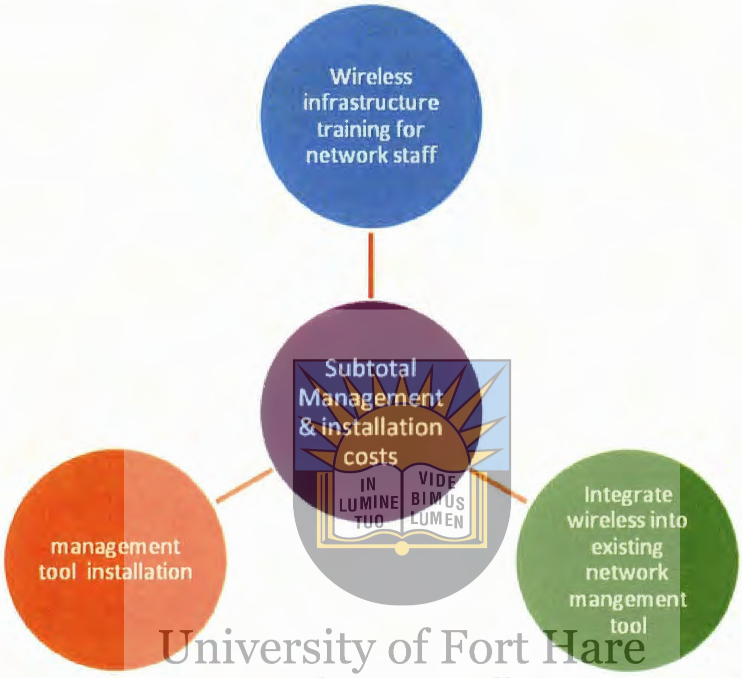


Figure 5.6: The Management and Installation reference model

5.2.5.1 Management Tool Installation

The management tool allows end-to-end management of the wireless network. This tool is packaged as an appliance with software application pre-loaded to support varying number of nodes for example the ProximVision can support a range of 25 to 1000 nodes. The management tool also supports remote configuration and provision of the entire wireless infrastructure thereby enabling centralized firmware distribution and management to in future reduce OPEX. It also helps to quickly identify trouble spots in the network. Some features that are provided by the management tool are:

i. User- based monitoring for real time information and quick trouble shooting.
ii. Rich security features- compliance audits, centralized policy definition (encryption, authentication method, passwords, e.t.c).
iii. Supports automated device discovery across any infrastructure be it LAN or WAN and
iv. Offers a single intelligent console to monitor, analyze and configure wireless

networks.

It is important to ensure the cost effectiveness of the management tool. The following attributes should therefore be considered when purchasing (Reynods, 2003: 148):

i. System design flexibility- the management tool should support AP hardware from a variety of vendors.
ii. It should be easy to upgrade.
iii. It should be easy to integrate with existing network infrastructure.
iv. It must be user friendly.
v. It must enable the control of everything from central location and should be able to change AP settings and,
vi. Ability to control

5.2.5.2 Wireless Integration

Integration is getting different hardware and technology platforms to work together. This includes ensuring interoperability with the operating system used through application programming interfaces (APIs). Network integration also promotes security and reliability with various network solutions such as internet security protocol (IPsec). Costs on wireless integration therefore come as a result of the use of various products such as windows server, visual studio and virtual server to mention a few.

5.2.6 The Wireless Network Cost Reference Model

Figure 5.7 shows the wireless network deployment cost reference model. The deployment cost reference model is shown using causal loops. Causal loops serve to enhance the model's insight and the understanding of its complex behaviour. The processes that feed back in the same direction are reinforced processes (R) since they amplify the conditions. Such "... causal relationships within the loop create exponential growth or collapse" (Reynods, 2003:1). This is shown by the increase of hardware costs, upon making changes that increase infrastructure costs. Each arrow in the causal loop diagram is labelled either with an O or an S. The O shows that the first variable makes a change in the opposite direction on the second variable for example in Figure 5.7 increased costs in design and planning which may come as a result of intense consultations with experts, high level survey that may involve spectrum testing may result to lower costs in management and installation costs for instance network integration becomes less complex and cheaper. The same is true for wireless installation, thorough and careful design and planning (which may come at a higher cost) tend to simplify installation and hence lower the costs of installation. The S label in the causal loop diagram shows that the first and second variables change in the same direction. In Figure 5.7 when costs of design and planning, network infrastructure, hardware, installation and management increase the deployment costs also increase. This is also the case when costs decrease. The wireless network cost reference model gives us a basis for deriving cost parameters for our cost model. In the following section we present an overview of the cost model.

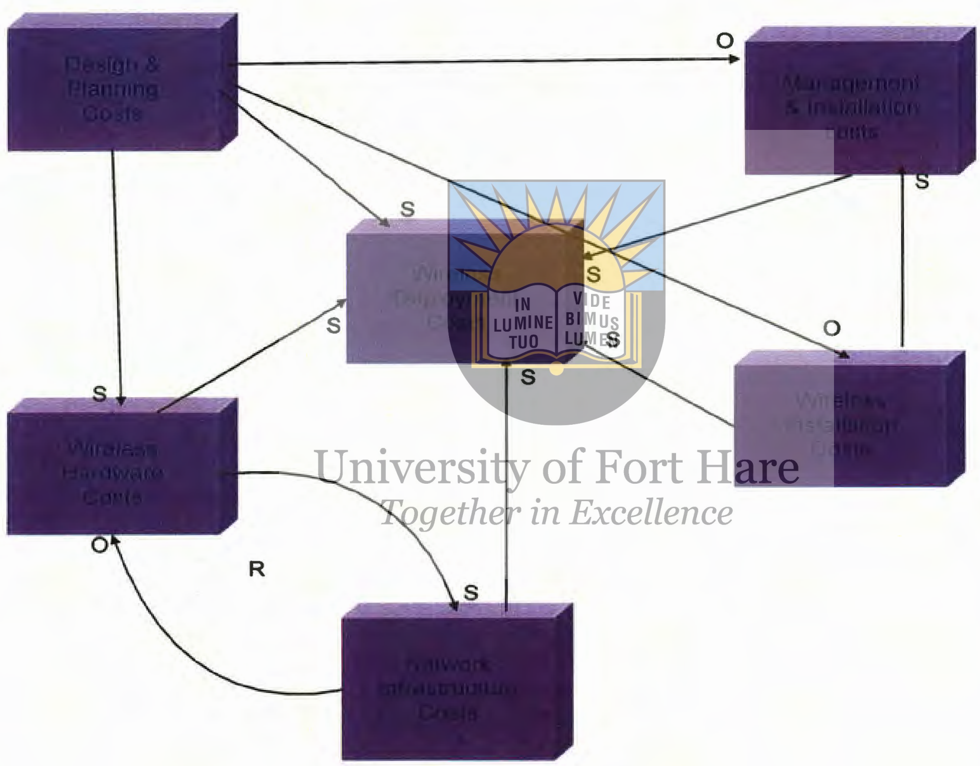


Figure 5.7: The Wireless network cost reference model

5.3 The Dynamic Adaptive Cost Model (DACM)

During the network deployment process numerous events occur that may cause adjustments to initially estimated costs. These adjustments are necessary for a cost management plan. This plan includes monitoring cost performance, ensuring that only appropriate changes are made to the network project. The events that may cause cost changes can not be entirely predicted as they are random in nature. They occur throughout different intervals of time and their occurrence tends to be independent of each other. Further if we consider very (sufficiently) small intervals of time during network deployment, the probability of having more that one event causing cost change is essentially zero (It is reasonable to assume that for a small interval of duration *(Δt)* the probability of two or more cost change events is negligible). If we let X denote the number of events causing cost changes in an interval of time, we can approximate the probability of having certain number of cost changes $P(X=x)$, where X is treated as a random variable. The events that cause cost changes can therefore be modelled using a Poisson process (Provided they comply with the conditions of a Poisson distribution discussed in chapter 4). We say that the random variable X has a Poisson distribution if its probability density function is of the form (Katsinis et al., 1996; Yue, 1991):

$$P(X = x) = \frac{\lambda^x e^{-\lambda}}{x!}, \qquad x = 0, 1, 2, \ldots, \tag{5.1}$$

Where $\lambda>0$.

From equation 5.1 it is easy to note that $P(X=x)$ enjoys the properties of the p.d.f (Jakes, 1993) because it is evident that $P(X=x)$ is greater than zero, and from the Maclaurin's series of expansion of e^{λ} (Lampret, 2001):

$$\sum_{x=0}^{\infty} \frac{\lambda^x e^{-\lambda}}{x!} = e^{-\lambda} \sum_{x=0}^{\infty} \frac{\lambda^x}{x!} = e^{-\lambda} e^{\lambda} = 1 \tag{5.2}$$

Thus equation 5.2 satisfies the conditions of a p.d.f. (that the summation of all the terms is 1) and so we can compute conditional probabilities. The mean of equation 5.2 is $E(X)$ and this is represented as (Katsinis et al. 1996; Yue, 1991):

$$E(X) = \lambda \tag{5.3}$$

The proof for equation (5.3) is beyond the scope of this work however Hogg and Elliot (988), Katsinis et al. (1996) and Yue (1991) elaborated on the proof. From equation (5.3) λ is therefore the mean of the cost of change events' distribution during the network deployment period. The mean is actually the product of the mean rate of occurrence and the estimated deployment period. In the model we assume that each cost change event or incident affects the deployment costs. Within the network deployment duration say T, a finite number of cost changes can be observed and recorded. These cost changes occur independently between small intervals of the duration of deployment and these can be enumerated as cost of change 1, 2, 3… n. We consider the cost of change in interval 1 to be C_1, for interval 2 to be C_2 and so on until the last interval n whose cost of changes is C_n. Here n is the positive integer which is an increase of the previous subscript of the cost of change by 1. For example in the cost of change C_1 the subscript is 1 and the subscript of the next cost of change is 2, which is derived from 1+1 (adding 1 to the previous subscript), this gives the cost of change C_2. Having all the costs of changes C_1, C_2, C_3,..., C_{n-1} and C_n, the total cost of changes can then be calculated as follows:

$$C_{tch} = C_1 + C_2 + C_3 + \cdots + C_{n-1} + C_n \qquad (5.4)$$

C_{tch} is the total cost of changes.

From equation (5.4) we can then use a special representation for compactly representing summation of many similar terms; the summation rule (Karp et al, 1992):

$$C_{tch} = \sum_{i=1}^{n} C_i \qquad (5.5)$$

Where C_i is a set of all cost of changes.

The subscript i represents the index of summation and n is the upper bound of summation. The successive values of i are found by adding 1 to the previous value of i stopping when i=n. Since the costs of changes are independent random variables, it follows that their summation C_{tch} is also a random variable (Karp et al, 1992). Two cases can be identified about cost change orders.

5.3.1 A Case of Normal Distribution

The distribution of cost change orders can either be normally distributed or not normally distributed. If we assume that the distribution is normal, from the definition of normal distribution C_i (the set of all cost changes) is normally distributed with a mean of μ_c and a variance of σ^2. Then the following relation can be established:

$$C_i \sim N(\mu_c, \sigma^2_c) \qquad (5.6)$$

The relation expressed in equation (5.6) indicates that C_i follows a normal distribution with a mean equal to μ_c and variance of σ^2. Considering that the cost of change orders C_i during network deployment consists of random variables *x* (where *x* represents the number of incidents causing cost changes) that follow a normal distribution, their linear sum is also normally distributed and thus:

$$C_{tch|x=n} = \sum_{i=1}^{n} C_i \qquad (5.7)$$

We now have to calculate the expected value of C_{tch} (since this gives the estimation of the total cost of changes for the network deployment) and this is done utilizing the general notation of an expectation *(E(X))* of a random variable *X*. The random variable here is the total cost of changes C_{tch}. Thus from the conditional distribution of C_{tch} (Touran, 2003):

$$C_{tch|x=n} \sim N(n\mu_c, n\sigma^2_c) \qquad (5.8)$$

This enables the computation of the expected value of the total cost of change as (Touran, 2003):

$$C_{tch} = E\left[\sum_{i=1}^{n} C_i\right] = E[X]\mu_c \qquad (5.9)$$

Hence the probability of a random variable *X* (representing the incidents causing cost change) given the number of cost changes can now be represented using the Poisson distribution (Katsinis et al., 1996; Yue, 1991):

$$P[X = n] = P[C_{tch} = N(n\mu_c, n\sigma^2_c)] = \frac{e^{-\lambda}\lambda^x}{n!} \qquad (5.10)$$

The distribution (DeGroot., 1986) that has been generated (equation (5.10)) serves as a tool to calculate the contingency costs with the user choosing the desired level of confidence. Estimating costs is not free from errors, therefore the confidence level indicate "the level of error we are willing to accept..." (Williams, 2002). Supposing that a level of confidence α is selected then the contingency needed would be 1- α. That will lead to:

$$P[C_{tch} \leq (1-\alpha)] \geq \alpha \qquad (5.11)$$

If we let $1-\alpha$ be δ then we have

$$P[C_{tch} \leq \delta] \geq \alpha \qquad (5.12)$$

$$P[C_{tch} \leq \delta] = \sum_{x=0}^{\infty} P[C_{tch} \leq \delta | X = x] P[X = x]$$

$$= \sum_{x=0}^{\infty} \Phi\left[\frac{\delta - x\mu_c}{\sqrt{x\sigma_c^2}}\right] \frac{e^{-\lambda}\lambda^x}{x!} \geq \alpha \qquad (5.13)$$

In other words we would need to have a contingency cost of δ such that equation (5.13) is true. This estimate gives guarantee that at a desired level of confidence, cost overruns are avoided.

5.3.2 A Case When Cost Change Orders are not Normally Distributed.

The other case is when the distribution of the cost changes is considered not normally distributed; this is the most prevalent case. The derivation of the probability mass function of the cost change orders takes a similar approach with the special case discussed above. This is because the total cost of changes during network deployment is a linear superposition of a large number of independent cost change orders which are random variables. Thus by the central limit theorem (DeGroot, 1986; Maurice K, et al, 1987) the cost of change orders (C_i) will still follow a normal distribution. Although the central limit theorem states that i has to be sufficiently large, Moder et al (1983) proved that even with i smaller than 10 the normality distribution is reasonably acceptable. Thus we still have:

$$C_i \sim N(\mu_c, \sigma^2_c) \qquad (5.14)$$

And

$$C_{tch|x=n} \sim N\left(\sum_{i=1}^{n} \mu_{C_i}, \sum_{i=1}^{n} \sigma^2_{C_i}\right) \qquad (5.16)$$

Equation (5.16) shows that the conditional distribution of the total cost of change follows a normal distribution with a mean which is a linear sum of the means of cost change orders from *i=1* to *i=n* where n is an integer. Its variance is also a linear sum of the variances of the cost change orders from *i=1* to *i=n.*

5.4 Expressing the Contingency Costs as a Percentage Ratio of the Original Costs

The cost of change orders can be expressed as a ratio of the original costs of the network project. Such a ratio expressed in percentage would help in determining the significance of each cost of change order. This ratio is known as the coefficient of variation or sometimes referred to as unitized risk. The coefficient of variation is usually used as a measure of precision for the dispersion of data sets (Tian L., 2005; Abercher H. S.A et al, 2006). The measure of dispersion is important to understand the standard deviation of the cost change orders in the context of its mean. The coefficient of variation of a random variable C_i (the cost of change order) with mean μ and standard deviation σ is defined by the ratio of the standard deviation to the mean. This ratio is expressed by the following equation:

$$Cv = \frac{\sigma_C}{\mu_C} \qquad (5.17)$$

The coefficient of variation provides a dimensionless measure of the variability of C_i relative to its mean and this parameter can then be used to express the cost of change order as the ratio of the total original network deployment cost. From the above equation (5.17) we can deduce that (making σ^2 to be the subject of the formula in equation (5.17);

$$\sigma_C = Cv\mu_C \qquad (5.18)$$

Where the standard deviation of the cost of change orders is σ_C, Cv is the coefficient of variation and μ_C is the mean of the cost of change orders. Expressing the cost of change orders as a ratio of the original network deployment costs we have (Touran A, 2003):

$$O_i = \frac{C_i}{C} \rightarrow O_i \sim N\left(\frac{\mu_C}{C}, \frac{Cv_C^2\mu_C^2}{C^2}\right) \qquad (5.19)$$

In this equation C_i is the cost of change order i, C is the original estimation of the cost of the wireless network project and O_i is the cost of change order as a percentage of the original project cost estimate. Hence the total cost of adjustment (O_{ch}) as a result of the cost changes throughout the wireless network deployment can be represented with the following equation (Touran, 2003):

$$O_{ch|x=n} \sim N\left(\frac{n\mu_C}{C}, \frac{nCv_C^2\mu_C^2}{C^2}\right) \qquad (5.20)$$

From equation (5.20) we can see that O_{ch} follows a normal distribution with a known value of the incidents that cause cost adjustments *(x)* to the network project cost. Consequently the probability of the total cost of changes being less than a certain assumed percent contingency (ω) can be obtained from the following equations;

$$P(O_{ch} \leq \omega) \geq p \qquad (5.21)$$

$$P(O_{ch} \leq \omega) = \sum_{x=1}^{\infty} P[O_{ch} \leq \omega | X = x] P[X = x] \qquad (5.22)$$

$$\sum_{x=1}^{\infty} P[O_{ch} \leq \omega | X = x] P[X = x] = \sum_{x=1}^{\infty} \Phi\left[\frac{\omega - \frac{x\mu_C}{C}}{\sqrt{\frac{xCv_C^2\mu_C^2}{C^2}}}\right] \frac{e^{-\lambda}\lambda^x}{x!} \geq p \qquad (5.23)$$

In the following section we show the calculation of the input values to the cost model.

5.5 Calculation of the Input Values to the Model

The Poisson process assumption made in our model was evaluated using data from a reputable telecommunications company in South Africa. The Centre of Scientific Industrial Research (CSIR) had provided us with some data for wireless network projects but it was not helpful as it had a lot of missing information like the number of incidents that were responsible for cost adjustments. The University of Fort Hare (SA) also implemented a wireless project at DWESA-CWEBE, a nature reserve in the Eastern Cape province in South Africa. However the data from the DWESA project could not provide us with what we needed as it had a lot of missing information, this included no records of actual days of the deployment, no recorded incidents that were responsible for causing the total cost of adjustment to the network costs and in most cases the cost of labour could not be determined as some of the work was performed at either Rhodes University (SA) or at the University of Fort Hare. From a pool of 18 different wireless projects deployed in semi rural and rural areas we managed to make use of 8 projects and discarded 10 as those either had a lot of missing information or the deployment time was too short to allow FOR any considerable number of cost change orders. The data obtained was then used to calculate inputs for our cost model. This data included the number of incidents causing cost adjustments to the original project costs, the cost of change orders, and the mean of the cost change orders as well as its standard deviation. The calculated inputs were then analyzed using a MATLAB routine and the results are reported in chapter six.

Table 5.1 shows a summary of the deployment costs for the 8 wireless projects used in the model. Each project is represented uniquely by the use of project identification code (project ID). Only attributes that are central to our model were captured for parameter calculation and analysis. The attributes considered were the original budget estimation, the number of changes that caused cost adjustments to the original budget estimate, the cost as a result of those changes and the original duration of each project estimated in the beginning. These attributes were then used to calculate various parameters that include the mean of change order costs, the standard deviation of change order costs, the coefficient of variation of change order costs, the mean of change as ratio of the original estimate, the cost of changes as ratio of the original estimate and the rate of change of events causing cost adjustments per week. Parameter calculation and analysis is presented in chapter six.

The number of projects used to calculate the inputs was 8 as have been mentioned. This tends to compromise the accuracy of the results as the margin of error increase with a decrease in a number of samples. To obtain better results the number of projects used to calculate the inputs needed to be increased. This would reduce the percentage error on the inputs. However the results obtained with 8 samples provided us with a reasonable model that could be used to arrive at very important decisions.

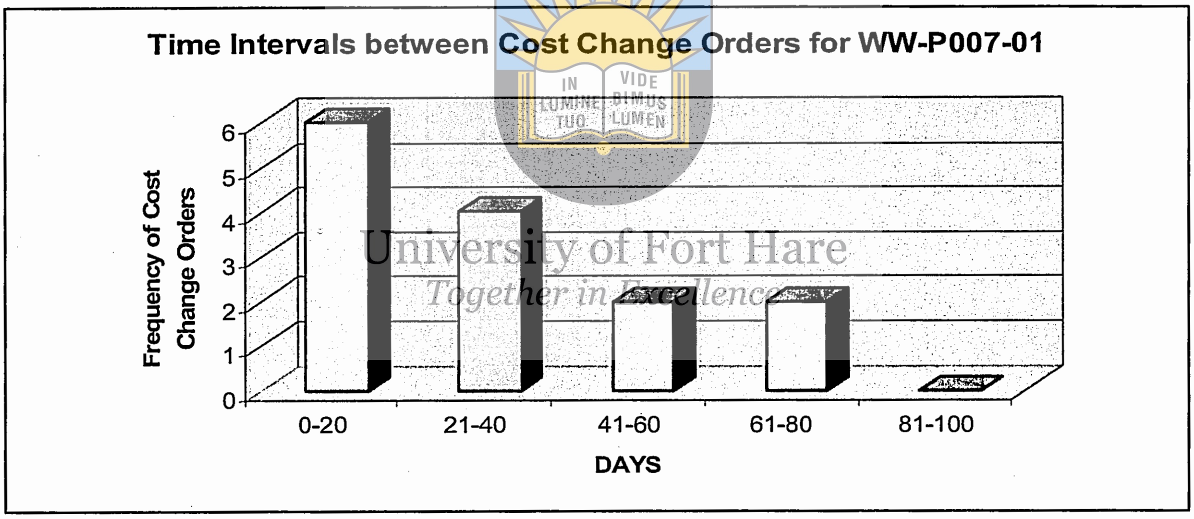
In the model we assumed that changes happen according to a Poisson process, which means that the time between changes is distributed according to an exponential distribution. The goodness of fit was performed on the 8 projects, and the results are provided in Chapter 6.

Table 5.1: The wireless projects' deployment costs

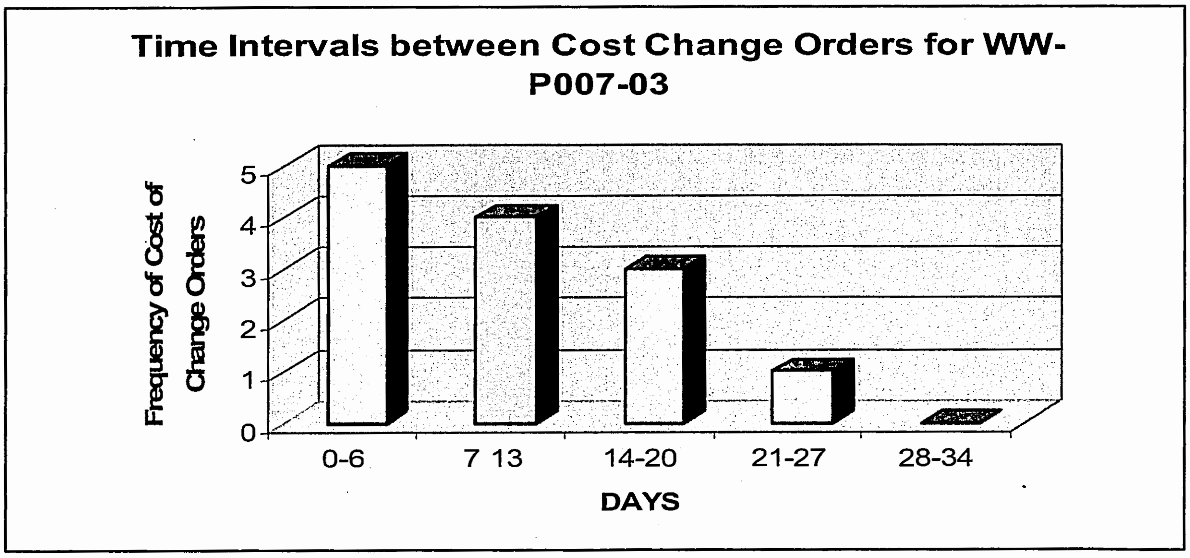
Wireless Project ID	Original Budget (R)	Number of changes	Cost of Changes (R)	Original duration (Days)
WW-P007-01	672408	14	129742	90
WW-P007-03	316920	13	77672	30
WW-P007-05	408613	13	63729	45
WW-P008-06	302246	5	33457	30
WW-P008-09	196015	4	16163	30
WW-P008-12	443032	6	34121	60
WW-P008-22	245388	6	33289	35
WW-P008-23	297405	6	24472	40

5.6 The Poisson Process' Goodness of Fit for the DACM

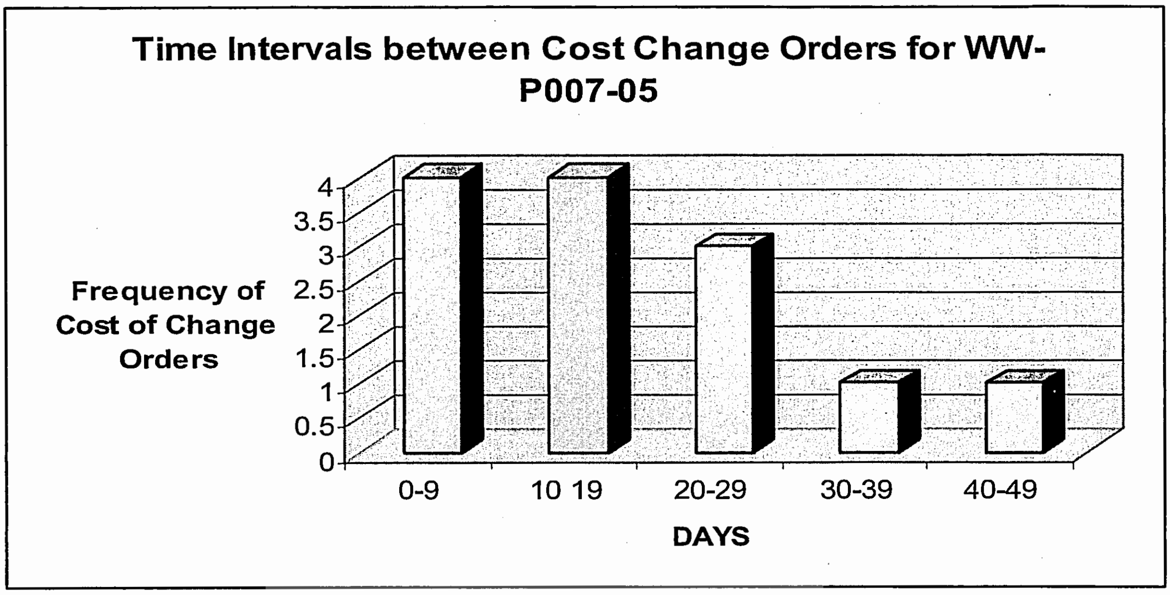
The visual approaches to determine suitability of applying a certain distribution to model a real world problem have become popular sometimes referred to as exploratory data analysis (Tukey, 1977). Visual tools that can be used include dot plots, histograms, probability plots and quartile plots. The idea is to use some graphics to gain a quick insight into the underlying distribution. The probability plots and quantile plots are seldom used. In our work we used the histogram as it is a simple graphical tool that is ease to interpret. We produced Histograms (Figure 5.8) to represent time intervals between costs of change orders in each wireless project used for our analysis. By visual inspection of Figure 5.8, we can note that in Figures 5.8 a), b), c), f), g) and h) the histograms show that the exponential distribution provides a better fit (the histogram resembles an exponential graph) to the time between costs of change orders during network deployment. Although Figures 5.8 e) and d) do not appear to fit the exponential distribution they visually approximate the normal distribution and that still does not affect the use of the exponential distribution as the Poisson distribution can be used to approximate the normal distribution (DeGroot H., 1986) of events causing costs of change orders. The common thing that we note with Figures 5.8 e) and d) is that they both had short times of project deployment (30 days). This could have limited the number of cost changes in time intervals and hence the exponential trend did not develop. However since 75% (6 out of 8) of the analyzed wireless network projects visually fit the exponential distribution we can safely model using the Poisson process.



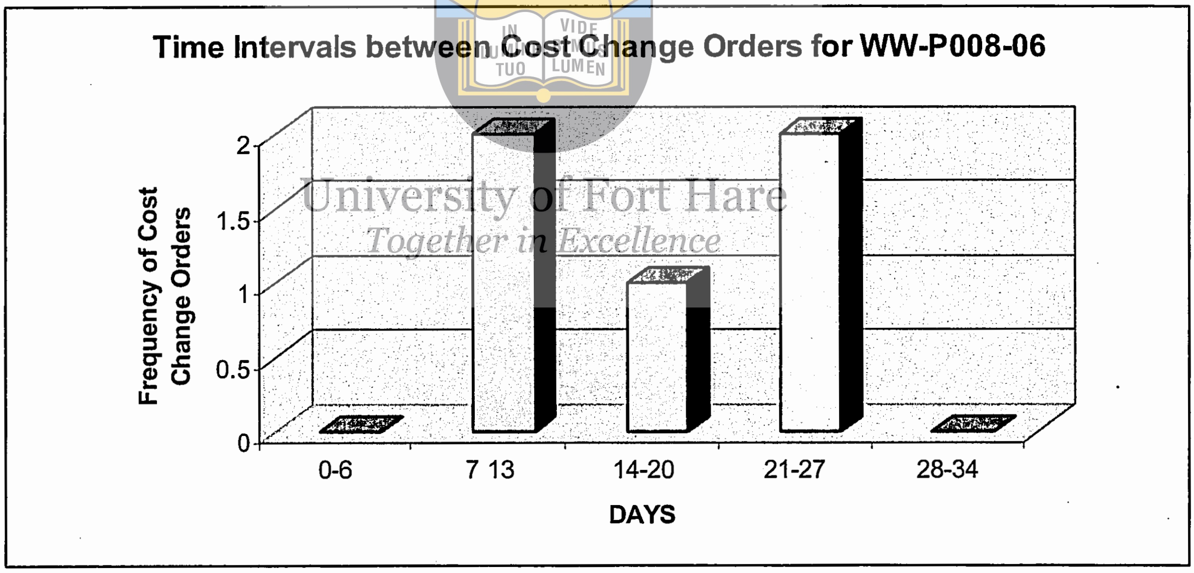
a): Time Intervals between Costs of Change Orders for WW-P007-01



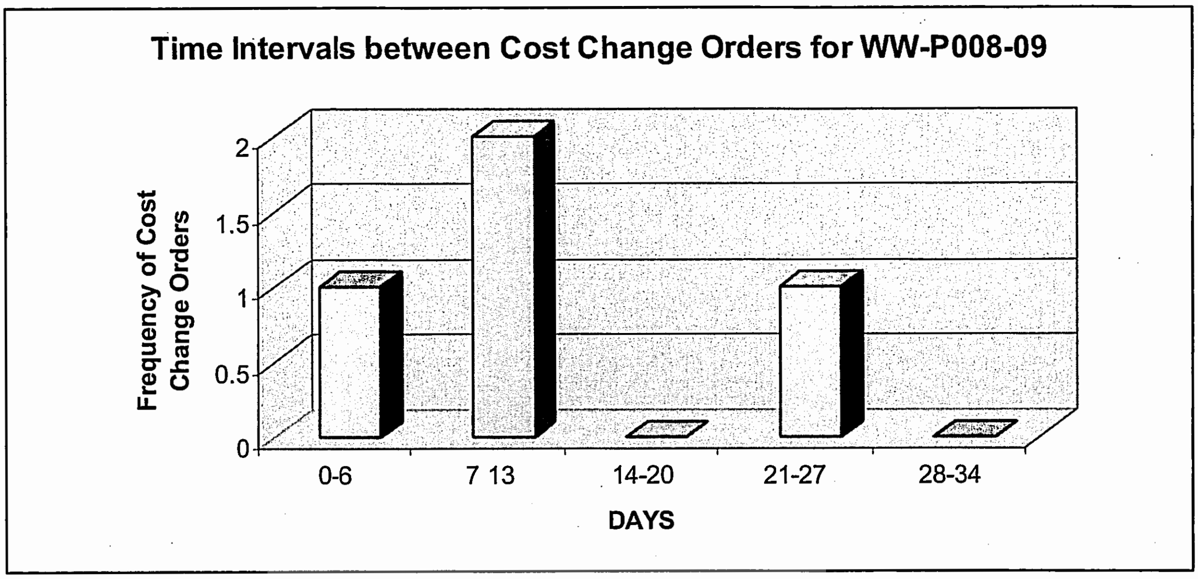
b): Time Intervals between Costs of Change Orders for WW-P007-03



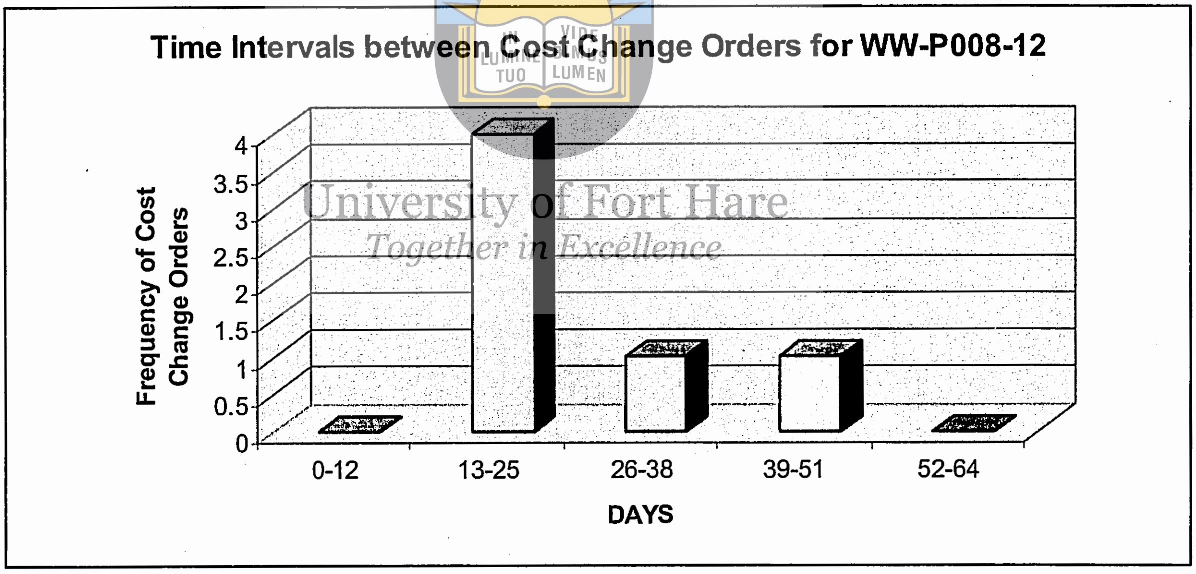
c): Time Intervals between Costs of Change Orders for WW-P007-05



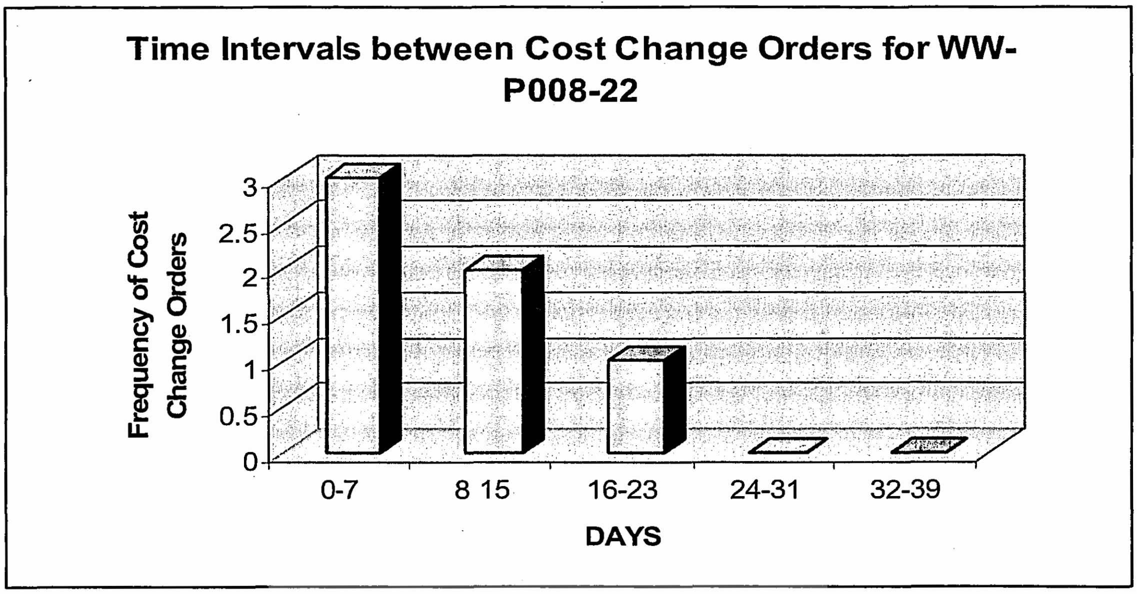
d): Time Intervals between Costs of Change Orders for WW-P007-06



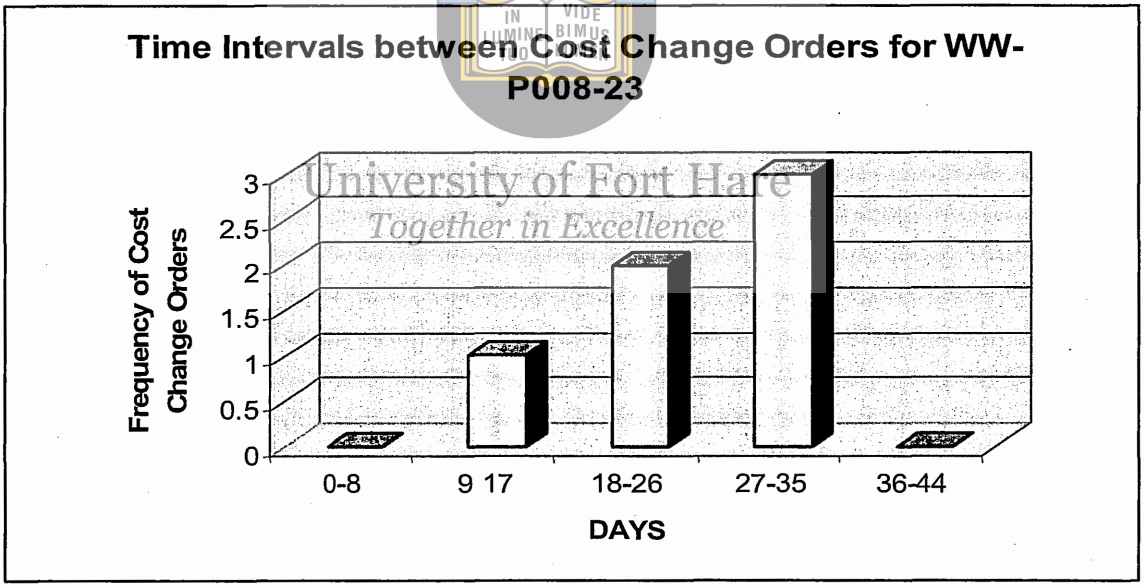
e): Time Intervals between Costs of Change Orders for WW-P008-09



f): Time Intervals between Costs of Change Orders for WW-P008-12



g): Time Intervals between Costs of Change Orders for WW-P008-22



h): Time Intervals between Costs of Change Orders for WW-P008-23

Figure 5.8: Time Intervals between Costs of Change Orders for the wireless projects.

5.7 Conclusions

Breaking up a problem space into basic concepts serves as a conduit for showing functionalities and organizational aspects of the core problem. In our approach to the cost model we designed reference models that encapsulate cost parameters and their interactions. The reference models discussed in this chapter include the planning and design costs, wireless hardware costs, network infrastructure costs, wireless installation costs and management costs. These also have various sub-entities that contribute to their overall cost as discussed in section 5.2. The cost model proposed in this chapter is formed out of a collection of reference models shown in Figure 5.7. Each of those reference models has the ability to be modified independently of others making it a modular cost model. Modularity enhances the DACM's ability to adapt to rapid cost changes without affecting other cost modules.

The derivation of equations which are central to the development of our cost model has also been shown. These include equations for expressing the contingency costs as a percentage of the estimated original costs of the wireless network project. The occurrence of the incidents causing cost changes happen at random intervals of time and those intervals have been graphically represented using histograms. The resultant histograms visually fit the Poisson distribution and this strongly buttresses our approach of using the Poisson process to develop the cost model. The summaries of costs for each wireless project studied and upon which parameters for the model are based were also presented in this chapter. The calculation of these parameters and their applications are discussed in Chapter six.

CHAPTER SIX

RESULTS AND DISCUSSIONS

6.0. Introduction

In this chapter we present the results that were obtained through the use of the DACM. One of the sensitivity analysis made was that of the mean of change of costs and the rate of occurrence of events causing cost adjustments to the contingency costs. Using the product moment correlation method we show that the mean of change of costs and the rate of occurrence have a positive correlation in a cause and effect way. We also consider how the probability of not having a cost overrun in a wireless network project is affected by various confidence levels. Furthermore the probability of cost overrun in a wireless network project is calculated using various chosen contingency ratios. The chapter also show how the expected value of the total cost of change is calculated using the average cost of change orders, the number of changes per week and the duration of network deployment as parameters. In particular the expected value of the total cost of change is variational with respect to these parameters. We also consider the expected contingencies using the risk neutral approach. The use of cost models has been questioned (Kassirer and Angell, 1994) because of the arbitrary nature of their construction. Questions surround the validity of the models especially because of the discretionary nature of the methods applied to construct them. In this chapter we provide an evaluation of our cost model using various techniques including the second order validation technique (Eddy, 1985). Finally we consider the limitations of the dynamic adaptive cost model.

6.1. The Wireless Network Deployment's Input Values and Statistical Parameters

Table 6.1 shows the parameters calculated from the studied projects. The table shows the mean of change order costs, the standard deviations of change order costs, the coefficients of variation of change order costs, the mean of change order costs expressed as a ratio of the original cost estimate of each project, the total cost of changes expressed as a ratio of the original estimate of each project and the rate of change of costs per week. For various sensitivity tests in the following sections we varied the ranges of different parameters according to the results of table 6.1.

Table 6.1: Input values and statistical parameters of wireless projects

Wireless Project ID	Mean Change order (Rands)	Standard deviation of change order (Rands)	Coefficient of variation of change order	Mean of change as ratio of the original estimate	Cost of changes as ratio of the original estimate	Rate of change per week
WW-P007-01	9267.3	10064.26	1.09	1.378226	19.29513	1.1
WW-P007-03	5974.769	10620.76	1.78	1.885261	24.50839	3
WW-P007-05	4902.231	13428.99	2.74	1.199725	15.59642	2
WW-P008-06	6691.4	5789.681	0.87	2.213892	11.06946	1.2
WW-P008-09	4040.75	2700.329	0.67	2.061449	8.245798	0.9
WW-P008-12	5686.833	7833.516	1.38	1.283617	7.701701	0.7
WW-P008-22	5548.167	5376.709	0.97	2.260977	13.56586	1.2
WW-P008-23	4078.667	11808.35	2.9	1.371418	8.22851	1.1

6.2. Rate of change of costs adjustments

We can actually learn more about how wireless projects' costs evolve by getting the mean of the costs, but this may be deceptive as it does not show how the costs change as the deployment of the project progresses. The best thing is to consider the rate of change in costs variables. This can be done in two ways, first by taking the first derivative of the cost function (Hennlock, 2009) to determine the marginal costs and secondly by plotting a graph. This gives us the picture of how marginal costs change as the incidents causing cost change increase. In this section we represent the rate of change of costs for the 8 projects that we used to calculate parameters for our experiment using a graph (Figure 6.1). Table 6.2 shows the duration of each wireless project, the mean of the distribution and the rate of change of costs per week in each respective project. The table shows that for wireless projects with a duration ranging from 4 weeks to 12 weeks the rate of change per week ranges from 0.7 to 3.0. The lower bound (0.7) is likely to result to relatively lower total cost of change while the upper bound (3.0) would certainly result to volatile marginal costs. The trend of the rate of change for the sample projects is represented in Figure 6.1.

Table 6.2: Rates of change and mean of distribution of costs for the wireless projects studied

Wireless Project ID	Original duration (Days)	Rate of change per week	Mean of the distribution
WW-P007-01	90	1.1	14.1
WW-P007-03	30	3	12.9
WW-P007-05	45	2	12.9
WW-P008-06	30	1.2	5.1
WW-P008-09	30	0.9	3.9
WW-P008-12	60	0.7	6
WW-P008-22	35	1.2	6
WW-P008-23	40	1.1	6.3

The Figure 6.1 shows that the rate of change of costs per week varied from project to project. Project WW-P008-12 with a mean of distribution of costs of 6.0 and duration of 8.6 weeks had the lowest rate of change of 0.7. The figure shows that when the duration becomes less and the mean of distribution remains the same the rate of change of costs increases, for example projects WW-P008-12 and WW-P008-22 had means of distribution of costs of 6.0 but their rates of change of costs are 0.7 and 1.2 respectively. Project WW-P008-22 whose deployment duration was 5 weeks compared to 8.6 weeks of WW-P008-12 had a bigger rate of change (1.2). An inverse case is when the duration remains constant and the mean of distribution of costs is varied. Examples for this are WW-P007-03, WW-P008-06 and WW-P008-09 from table 6.1; they all have durations of 4.3 weeks. The three projects however had different values of mean of distribution of cost change as well as their rates of change of costs. From Figure 6.1 it can be seen that a small difference between the duration and the mean of distribution of cost change produces a smaller rate of change of costs when the duration is constant. As the difference between the two parameters increases the rate of change of costs also increases. This is referred to as a cause and effect relation[9]. However an inverse of the previous observation is true when the duration varies and the mean of distribution is kept constant (e.g. projects WW-P008-12 and WW-P008-22 both had a mean of distribution of 6.0). In this case as the difference between the duration of the project and its mean of distribution of costs change increases, the rate of change of costs decreases and as the difference between the two parameters decreases the rate of change increases (e.g. a project duration of 8.6 weeks and mean of distribution of 6.0 produces a rate of change of 0.7 and a duration of 5 weeks and a mean of distribution of 6.0 had a rate of change of costs of 1.2). It is algebraically correct to say a higher rate of change of costs leads to higher total costs of changes in the whole wireless project (of course assuming that each cost of change is a substantial value). This means that contingency costs can be determined depending on the differences between the duration of the project and the expected mean of distribution of cost changes. A wireless project with less expected mean of distribution of costs would require smaller contingency costs than a project with more expected distribution of costs of changes. Based on the above revelations it can be noted that both the mean of change of costs and the rate of change of costs are important parameters in determining the contingency costs for a wireless network project. In the following section we consider the correlation between those two parameters.

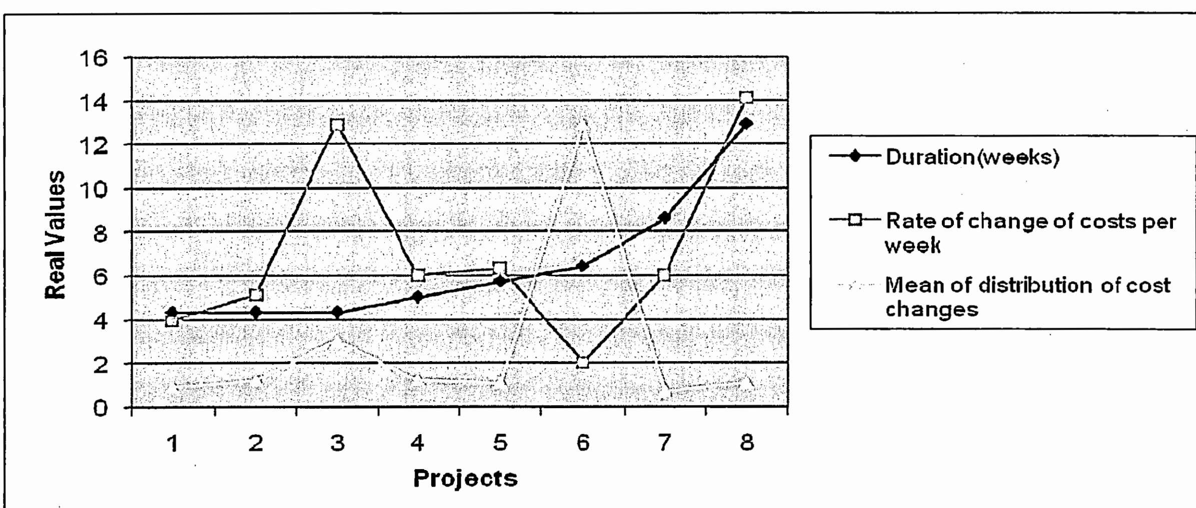


Figure 6.1: The rate of change of costs

[9] In the context of this thesis cause and effect is considered to be a proportion of an increase/decrease in one variable that causes a same proportion of increase/decrease in another variable

6.3. The Correlation of the Mean of Change of Costs and the Mean Rate of Occurrence

It is of interest to know if the mean of change of costs and the mean rate of occurrence of cost change orders have a positive or negative correlation. A positive correlation would trigger a higher mean of cost of changes in the project and a negative correlation would indicate the opposite. We can determine the correlation by finding the product moment correlation coefficient *(r)* of the two parameters. The product moment correlation *(r)* is a numerical value between -1 and 1 inclusive which indicates the linear degree of scatter. This means that $-1 \leq r \leq 1$. We have three conditions (Crawshaw and Chambers, 2001):

1. $r = 1$ indicates perfect positive linear correlation
2. $r = -1$ indicates perfect negative linear correlation
3. $r = 0$ indicates no correlation

To carry out the task we applied the following equation (Crawshaw and Chambers, 2001):

$$r = \frac{s_{ccrc}}{s_{cc} s_{rc}} \qquad 6.1$$

Where:

$$s_{ccrc} = \frac{\sum cc}{n} - \bar{cc} * \bar{rc} \qquad 6.2$$

$$s_{cc} = \sqrt{\frac{\sum cc^2}{n} - \bar{cc}^2} \qquad 6.3$$

$$s_{rc} = \sqrt{\frac{\sum rc^2}{n} - \bar{rc}^2} \qquad 6.4$$

In the above equations S_{cc} is the variance of the change of costs and S_{rc} is the variance of the rate of occurrence of incidents causing cost change. S_{ccrc} is the covariance connecting the mean of change of costs and the mean rate of occurrence of cost change orders.

The mean of change of costs and the mean rate of occurrence of incidents causing cost changes were analysed to determine the correlation between those two parameters. Below we show the computation of the product moment correlation coefficient. Let the mean of change of costs be *cc* and the mean rate of occurrence be *rc* with $\bar{cc}$ and $\bar{rc}$ being their mean of distributions respectively. Then:

From Table 6.3 using equation (6.2) $s_{ccrc} = \frac{19.20352}{8} - (\frac{13.65}{8}) \times (\frac{11.2}{8}) = 0.006$

Using equation (6.3) $s_{cc} = \sqrt{\frac{24.68}{8} - (\frac{13.65}{8})^2} = 0.401$

Using equation (6.4) $s_{rc} = \sqrt{\frac{19.6}{8} - (\frac{11.2}{8})^2} = 0.7$

Therefore using equation (6.1) $r = \frac{0.006}{(0.401) \times (0.7)} = 0.02$

The product moment correlation coefficient is 0.02 indicating that there is some significant positive linear correlation. The linear positive correlation between the two variables indicates that the higher number of mean rate of occurrence of cost change orders leads to a higher mean of cost of change orders. However, a significant correlation does not necessarily mean cause and effect; there are other parameters that play a role e.g. the project duration as discussed in Section 6.3.

Table 6.3: Values of the mean cost of change and the mean rate of occurrence

cc	rc	cc^2	rc^2	$cc*rc$
1.378226	1.1	1.899507	1.21	1.516049
1.885261	3	3.554209	9	5.655783
1.199725	2	1.43934	4	2.39945
2.213892	1.2	4.901318	1.44	2.65667
2.061449	0.9	4.249572	0.81	1.855304
1.283617	0.7	1.647673	0.49	0.898532
2.260977	1.2	5.112017	1.44	2.713172
1.371418	1.1	1.880787	1.21	1.50856
$\sum cc$ =13.65457	$\sum rc$=11.2	$\sum cc^2$ =24.68442	$\sum rc^2$ =19.6	$\sum cc*rc$=19.20352

6.4. The Effect of the Contingency Costs on the Confidence Levels

Different contingency ratios give different confidence levels that may reflect on various other parameters used to calibrate a cost model. It is important to analyse the effect of the contingence costs on the confidence levels that result to adequate cost estimates.

Adequate cost estimates are project cost estimates that do not result to cost overruns. To explore the contingency costs and confidence levels' problem space we used the 8 projects selected for the calculation of our model parameters. The inputs that we used included the mean of the cost of change for each wireless project, the variance of cost of change, assumed contingency and the mean of the distribution for each project. A MATLAB routine was then created using these parameters and Figure 6.2 shows the results of the experiment. Figure 6.2 shows that the confidence levels of not having cost overruns increase steadily with the increase of contingency costs. This is true for all the contingencies ranging from 1% to just fewer than 20%. As shown in Figure 6.2 when the contingency costs are 20% or more of the original project cost the confidence levels tend to be more or less constant. We can certainly state a case that for wireless network deployments, contingency costs of 20% would be adequate most of the time as anything more than that does not significantly change the confidence level of not having a cost overrun.

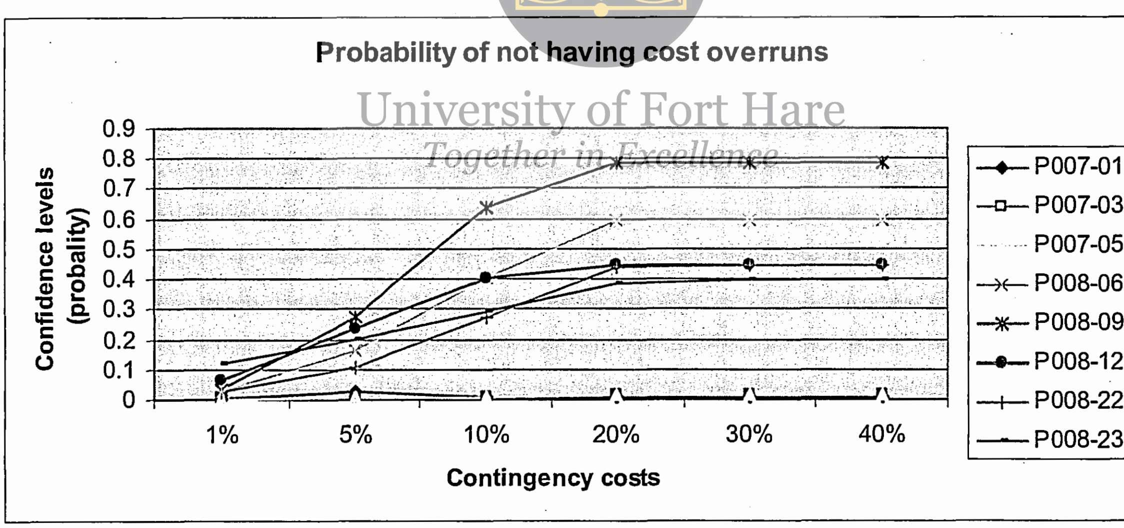


Figure 6.2: The probability of not having cost overruns

6.5. The Effect of the Coefficient of Variation on the Probability of Cost Overrun

We computed the probability of cost overrun given a contingency of 10% and various values of the mean of cost and various values of the coefficient of variation. We assumed a project of duration of 8 weeks. The coefficient of variation was tested whether varying it caused significant changes to the probability of cost overrun. Using computed values in Table 6.4 we calculated the product moment correlation of those two variables (coefficient of variation and the probability of cost overrun) using the same equations as in Section 6.4. The result was:

S_{ccrc}	S_{cc}	S_{rc}	r
-0.00323	2.60E-03	1.743746	-7.14E-01

That is $r = \dfrac{-0.00323}{4.53E-03} = -7.14E-01$

Table 6.4: Calculation of the product moment correlation

	Probability of cost overrun (pco)	Coefficient of variation (cv)	pco^2	cv^2	pco*cv
	0.00268	0.67	7.20225E-06	0.4489	0.001798
	0.00268	0.87	7.20225E-06	0.7569	0.002335
	0.00268	0.97	7.20225E-06	0.9409	0.002603
	0.00268	1.09	7.20225E-06	1.1881	0.002925
	0.00268	1.38	7.18785E-06	1.9044	0.0037
	0.00264	1.78	6.95521E-06	3.1684	0.004694
	0.00242	2.74	5.86238E-06	7.5076	0.006634
	0.00235	2.9	5.52305E-06	8.41	0.006815
sum	0.020824	12.4	5.43375E-05	24.3252	0.031505
Average	0.002603	2.755556	6.79219E-06	3.04065	

Since r is negative we conclude that the probability of cost overrun is less sensitive to the variability of the coefficient of variation. Therefore since the main inputs of the model are the mean of cost change, coefficient of variation and the total number of changes the coefficient of variation can even be taken to be constant.

6.6. The Probability of Cost Overrun

To reflect on the probability of cost overrun we varied various contingency costs and calculated probabilities of having cost overruns. In this case we considered the coefficient of variation to be constant. The coefficient of variation was taken to be constant because as we indicated, the probability of cost overrun is less sensitive to the coefficient of variation. The Figures 6.3 and 6.4 show the probability of cost overrun with 10% and 20% contingencies respectively. Both figures show that the probability of cost overrun in wireless network projects is more sensitive to the rate of change of costs and also to the mean of change of costs. In Figure 6.3 it can be seen that a higher mean of cost change combined with a higher rate of change of occurrence results to a higher probability of cost overrun. However, when the assumed contingency increases, the probability of having a cost overrun decreases. Figure

6.4 shows that when the assumed contingency is 20% the probability of having a cost overrun tends to be less. For example in figure 6.3 where assumed contingency is 10% of the original project cost estimate and 1.0 rate of change of costs per week, the probability of having a cost overrun is more than 0.8 which is very high. With the same rate of change of costs when contingency costs are assumed to be 20% the probability of having a cost overrun falls under 0.4. It can actually be noted that the probability of cost overrun is reduced by 52% when assumed contingency is raised from 10% to 20%. This is quite a substantial reduction.

A case can be stated here that a higher cost contingency tend to reduce the risk of having a cost overrun in a wireless network deployment project irregardless of the rate of change of costs. Of course, these results completely rely on what values we have studied for each parameter (e.g. rate of change of costs per week ranges from 0.7 to 3.0 and project duration ranges from 30 days to 90 days), which is shown in Table 2. So at this point we can not generalize which parameter has the largest impact on nominal cost overruns. These results only demonstrate the capability of the model to estimate cost overruns as well as its variability based on these parameters. If one gives values of these parameters for a specific wireless project, the possible overruns and its variability can be estimated by the proposed model.

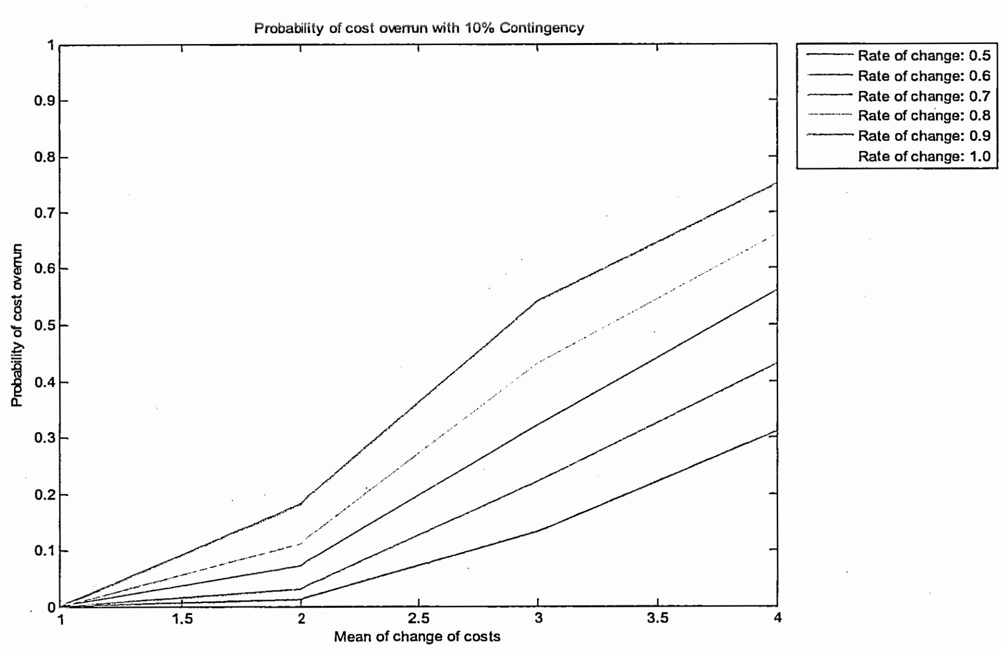


Figure 6.3: Probability of cost overrun with 10% contingency

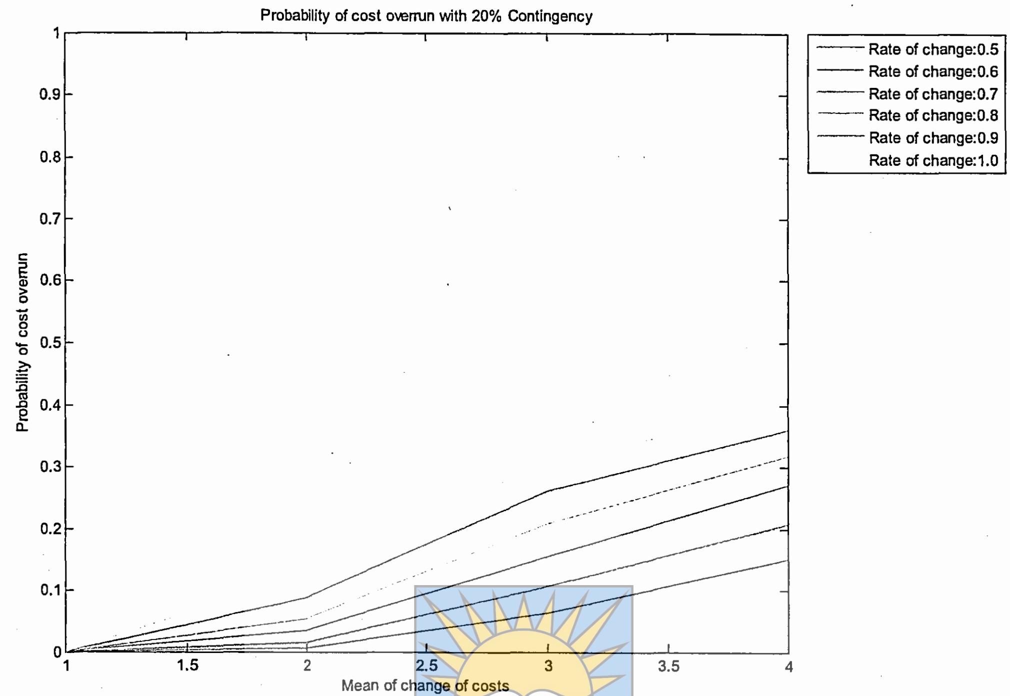


Figure 6.4: Probability of cost overrun with 20% contingency

6.7 The Expected Total Cost of Change

The cost of adapting to wireless network project costs requires knowledge about what effects the cost of change will have on the total deployment costs, what the options are for responding to those changes, and how much those options will cost. Determining what effects the cost change will have can be done using various risk analysis techniques (Schwalbe, 2007). The knowledge of how much the cost of change is likely to be the key to cost estimation of the whole project deployment. In this section we show that our cost model calculates the expected total cost of adjustment as a result of various changes in the wireless network project. In chapter five we showed that if X is a random variable denoting the number of incidents causing cost change during the project deployment and O_i is the cost of change order as a percentage of the original then the expected cost of change (E[O_{ch}]) can be calculated as follows (Touran, 2003, Benjamin and Cornell, 1970):

$$E[O_{ch}] = E[X].E[O_i] = E[X].\frac{\mu_c}{C} = \lambda.\frac{\mu_i}{C} \qquad 6.1$$

λ is the mean of distribution of costs.

μ_c is mean of change order costs and

C is the original cost estimate of the project excluding contingency costs.

Table 6.5 shows two examples of calculating the expected value of the total cost of change.

Table 6.5: Calculation of the expected value of the total cost of change

Number of changes per week	Average change order cost as a % of the original estimate	Period of network deployment	Expected value of the total cost of change
1	1	8	8%
2	2	8	32%

The table shows that for an 8 weeks wireless project if the average change order cost is 1% of the original project cost estimate and given that there is 1 change per week the expected value of total cost of change is 8%. For an average change order cost of 2% given 2 changes per week the expected value of total cost of change would be 32%. Using a risk neutral approach (the assumption being that some projects will overrun while others will under run and, in the long run, they will balance out), it means that a contingency cost of 8% would be needed about 50% of the time for an 8 weeks wireless network project given that there is 1 change per week and the average change order cost is 1%. For an 8 weeks project given 2 changes per week and 2% average change order cost, a contingency of 32% would suffice 50% of the time. Under this circumstance it follows that given an average change order cost, duration of network deployment and the number of changes per week we can calculate the expected value of the total cost of change. By increasing the contingency one would reduce the probability of having a project cost overrun.

6.8. The Actual Total Cost of Change Order and the Expected Total Cost of Change Order

To strengthen case on the accuracy of the DACM in estimating the total cost of change we used the model to calculate the expected values of cost of change order for the 8 projects that we used for calculating our model parameters. For simplicity we took α (the mean rate of occurrence of changes) to be 1.4. This was the average mean rate of occurrence for wireless network projects with deployment period ranging from 4 weeks to 12 weeks. We then used a MATLAB routine with equation (5.19) to compute the expected value of total cost of change. Figure 6.6 represents the actual costs of change and the expected costs of change for the 8 projects. Except for only two projects WW-P007-03 and WW-P007-05 whose expected values remained below the actual values, the rest had expected value costs of change remaining above the actual value costs of change as shown in figure. We can justifiably use the fact that 6 out of 8 (which represents 75%) expected values remained above the actual values to draw an inference that the expected values obtained through the use of the model tend to sufficiently provide the required cost contingencies. With sufficient contingency costs estimated, the uncertainties associated with wireless network deployment are catered for. To make such conclusions we need to check the validity of our cost model. In the following section we validate the DACM.

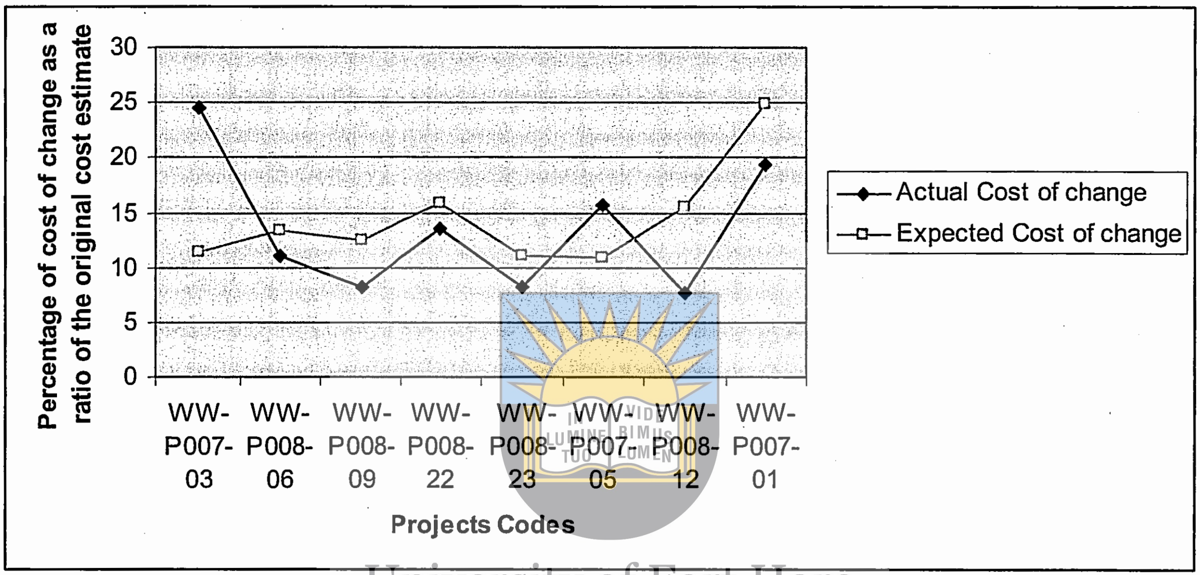


Figure 6.5: actual costs of adjustment versus expected costs of change

6.9. Model Evaluation

The utility of the model was evaluated by using empirical data. As we were in the process of trying to collect empirical data, we followed some of typical validation aspects for simulation studies (Sargent, 1999), which have been applied in (Nonaka et al, 2007). The proposed model is considered to be reasonably valid under the assumptions described in chapter 5, because the proposed formulas are partly supported by several empirical observations as stated in chapter 5 section 5.4. Data validity as input to the model is also supported by these empirical observations in terms of determining the distributions of the incidents that cause cost changes during wireless network deployment. The model predictions were compared with data used to estimate the model parameters and sensitivity tests provided transparency with regard to the model's cost effectiveness. However, there are some limitations of the model, as discussed in section 6.10.

6.10. Limitation of the Model

One of the most important limitations of this study is that the proposed model is based on mathematical functions which make it to be a deterministic model. This means that the output is determined specifically when the inputs have been furnished. To calculate the input parameters for the wireless network projects one needs to consider a number of variables that includes duration of the project as well as the number of incidents that trigger cost changes. The number of incidents that cause cost change can only be significant if the duration of the project is considerably long. However some wireless projects can take very little time to be deployed and turn to be unnecessary to use the model. Also the model could be better validated with more data from different companies unfortunately as we have indicated earlier on it was not easy to obtain financial data from companies.

6.11. Conclusions

The input values and statistical parameters useful to our cost model have been calculated. The analysis of the rate of change of cost adjustments has shown that contingency costs can be determined depending on the differences between the duration of the project and the expected mean of distribution of cost changes. A wireless project with less expected mean of distribution of costs would require smaller contingency costs than a project with more expected distribution of costs of changes. Most uncertainty costs in wireless network projects would be adequately covered with a contingency of 20%. The results presented in this chapter demonstrate that our cost model is capable of estimating reasonable nominal cost overruns and its variability. We have shown that the expected values of change order calculated using the model provides sufficient contingency costs. This also gives a validation of the model by producing expected values that are closer to the actual change order costs. This certainly shows a good level of accuracy in using the DACM to approximate the total costs of a wireless project, this includes the contingency costs. Although the model approach is generic and can apply to any network deployment cost model it is in particular valid for wireless network deployment in rural environments as parameters used were calculated from such projects. More concluding remarks are given in the following chapter.

CHAPTER SEVEN

CONCLUSIONS AND FUTURE WORK

7.0. Introduction

This thesis has exposed a relevant problem in the current cost estimating techniques used for communication network deployments. Various relevant cost models were discussed and in this chapter we present our observations on those cost estimation techniques. The development of this work has made us to make a number of achievements; these are also discussed in this chapter. Finally we suggest future extensions on this work.

7.1. Analysis of other cost models

A number of innovative cost models were identified and discussed. These include neural networks cost models, fuzzy analogy models, mean and least square regression cost models, method of scales cost models and engineering cost models. We have shown that although neural networks are capable of handling complex data and capable of adapting to new cost environments, to accurately train the neural network needs a big data set which sometimes is not available. In addition one has to choose a sufficiently complex network structure to train the neural network to a desired mapping for cost function approximation and that remains a big challenge. Neural network cost estimation models also provide little benefit in terms of sensitivity analysis of the relationships between inputs and outputs. This is because of their iterative nature; iterative neural network may be oscillatory producing more complications and instability of the model (Cohen, 1992; Blum, 1992). The fuzzy analogy cost models deal with attributes that are measured using categorical quantifiers. Although their ability to deal with categorical quantifiers is commendable we have demonstrated in this thesis that fuzzy analogy cost models suffer subjectivity inherent from their adaptation process where parameters are adapted to similar projects that have already been deployed. A mean least square regression cost model uses a linear association of cost variables to predict the missing values. We have shown that this method is limited because of sensitivity to outliers as it has poor extrapolating properties. As the range of the data increases it becomes difficult to linearly fit data into a model. Another cost model presented in this thesis is the method of scales which is based on the assumption that average costs of deploying a network increases with capacity or size. However, we have shown that most cost models tend to be modelled through nonlinear cost relationships (Cost estimation, 2005) between network deployment costs and network size or capacity. Finally the engineering estimation cost model was discussed and we found that it is expensive and needs a lot of time. In addition to that because the method requires an analyst with extensive knowledge of engineering analysis, this may not be available thereby limiting the use of the method.

7.2. Achievements

This thesis developed a novel probabilistic cost model for wireless network deployment. The reference cost models that we designed in this work encapsulate most of the cost parameters of wireless network and their interactions. This helped in mapping of parameters into cost functions and parameter calculation for sensitivity analyses. One of the achievements that we made through this work was to acquire an understanding of the nature of the costs that are directly associated with wireless network deployment. Understanding the cost variables became a foundation for our cost model construction. In this thesis we have proposed an innovative cost model for wireless network deployment. The model caters for uncertainties that may arise during the deployment process. Those uncertainties are provided for through contingency costs that are estimated through the model. By estimating expected values of total cost of change orders we have managed to propose a cost model that would provide adequate contingency costs. The model also allows the estimator to choose the level of confidence commensurate with the risks associated with each individual wireless network project. The proposed cost model further provides for a platform to perform various sensitivity tests to optimize project cost estimation. Finally our main objective has been achieved; that of a building a cost model which factors in uncertainties that arise during wireless network deployment. We have shown that a cost model can be made to adapt to a dynamic cost environment through the use of a Poisson process that adequately deals with uncertainties caused by random cost change orders during project deployment.

This thesis shows that using a Poisson process approach can be successful for estimating projects costs and it is good news for further researches maybe incorporating Markov process to get better results forecasting.

7.3. Future Extension

The calculations of model parameters was based on wireless networks deployed in rural and semi-rural areas making the cost model relevant for deployments in rural environments. There are peculiarities that influenced the calculation of parameters; things like free land to build network infrastructure or sometimes infrastructure was provided by schools or municipalities. Some of the equipment were usually donated hence had no recorded costs. Parameters would be different under urban environments hence we believe that various wireless projects in various environments can be studied to produce parameters that can be used for a universal wireless network cost model. This work can be further extended to include a probabilistic routine that would estimate the occurrence of incidents that may cause changes to initial wireless network project costs.

APPENDIX A: Computing the error probability

To write our MATLAB program for computing the error probability let us assume the two error probabilities (these values are commonly used for two state models) (Pathak and Agawal, 2003):

$$Pr\{E|ac\} = 0.0005 \qquad (3.17)$$

$$Pr\{E|unac\} = 0.1000 \qquad (3.18)$$

From equation (3.16) the error generation matrix B becomes:

$$B = \begin{bmatrix} 0.9995 & 0.9000 \\ 0.0005 & 0.1000 \end{bmatrix} \qquad (3.19)$$

As a simple example let the Markov chain matrix be:

$$B = \begin{bmatrix} 0.9995 & 0.9000 \\ 0.0005 & 0.1000 \end{bmatrix} \quad (3.18) A = \begin{bmatrix} 0.98 & 0.02 \\ 0.05 & 0.95 \end{bmatrix} \qquad (3.20)$$

The MATLAB program for computing the error probability

```
% file: ErrorProbability.m
N=100000;                        %number of iterations
state = 'acceptable';            %initial state
A = [0.98 0.02; 0.05 0.95];          %state transition matrix
B = [0.0005 0.1000];                 %second row of B
out = zeros(1,N);                %initialize matrix
errors = 0;
for i = 1:N
    error = 0;                   %initialize error counter
     y = rand(1);                %RV for state transition
     err = rand(1);              %RV for error given state
    if state == 'acceptable';    %test for acceptable state
            if y < A(1,1)
                    state = 'acceptable';    %remain in acceptable state
                    if err<B(1);             %test for error
                    error = 1;       %record an error
            end
    else
       state ='unacceptable';    %transition to unacceptable levels
       if err < B(2);        %test for error
```

```
            error = 1;                    %record an error
          end
        end
      else                              %state = unacceptable
        if y <A(2,2);
            state = 'unacceptable';   %remain in unacceptable state
            if err < B(2);            %test for error
               error = 1;             %record an error
            end
      else
          state = 'acceptable';       %transition to acceptable state
          if err < B(1);              %test for error
             error =1;                %record error
          end
        end
    end
    errors = errors + error;          %increment error counter
    PE = errors/N;                    %calculate probability
%end of script file.
```

APPENDIX B: Training the Perceptron

```
%MATLAB Program for training the perceptron
%File: c7_uni2exp.m
clear all                                   % be safe
n= input('Enter number of points> ') ;
b=3;                                        % set pdf parameter
u = rand(1,n) ;                             % generate U
y_exp = -log(u)/b ;                         % transformation
[N_samp,x]=hist(y_exp,20) ;                 % get histogram parameters
subplot(2,1,1)
bar(x,N_samp,1)                             % plot histogram
ylabel('Number of  Samples')
xlabel('Independent Variable-x')
subplot(2,1,2)
y=b*exp(-3*x) ;                             % calculate pdf
del_x=x(3)-x(2) ;                           % determine bin width
p_hist= N_samp/n/del_x;                     % probability from histogram
plot(x,y,'k',x,p_hist,'ok')                 % compare
ylabel ('Probability  Density')
xlabel('Independent Variable - x')
legend ('true pdf' , 'samples from histogram',1)
% End of script file.
```

Appendix C: Wireless Projects Description

Most of the projects used in this research were intended to provide first mile and first inch wireless connectivity into schools in rural areas of South Africa and in some cases extending to local businesses. The first mile connectivity is a common implementation amongst all the rural schools as the links between the schools and the base stations was delivered using the ISM frequency band.

For the schools without a wired Ethernet LAN, a wireless LAN using WiFi 802.11b/g standard had been deployed in computer labs. For those with a wired LAN the wireless data internet connectivity was provided through a Linux box (Ethernet hub) that is distributed to the networked computers. The Linux was preferred in most of the wireless projects because it is an open source and that reduces deployment costs. In some instances WiMAX 802.16b was used for the network deployment while in some the two WiFi and WiMAX were deployed together. All the rural network deployments we studied used the 2.4 GHz frequency band do a link budget, and provided a point-to-point link from base stations to schools.

PROJECT NAME: WW-P007-01						
	Cost	Changes	Nature of changes	cost of changes	Original Costs	Cost of change
Design and Planning Costs						
consulting	$6 000	1	rising cost	$600	43200	4320
RF design	$3 000	2	rising cost	$100	21600	720
Infrastructure design	$4 300				30960	0
Project management					0	0
					0	0
Network Infrastructer					0	0
Infrastructure Installation (5 days labour at $1,250 per day)	$6 250	1		$1 250	45000	9000
Infrastructure Cabling	$2 300				16560	0
Infrastructure Hardware(Appr. 6 new POE switches)	$15 000	1	weak rand(11.0)	$4 091	108000	29454
					0	0
Wireless Hardware					0	0
Aps (200 Aps at $50 each)	$10 000	1	weak rand (9.5)	$1 578.95	72000	11368
Controllers (12 Allied Telesyn AT-FS750-24 PORT at $720	$8 640				62208	0
					0	0
Wireless Installation					0	0
Installation (10 days labour at $1,125 per day)	$11 250	2		$2 250	81000	16200
User training (8 days labour at $1,150 per day)	$9 200	1	(catering)	$800	66240	5760
Go live support (1 day labour at $1200 per day)	$1 200				8640	0
Wireless Certification	$3 500				25200	0
					0	0
Management and Integration					0	0
Management tool Installation (3 days at $1,850)	$5 400	1		$1 800	38880	12960
Intergrate wireless into existing network management tool (3 days at $1250 per day)	$3 750	3	(increase no. of days)	$3 750	27000	27000
Wireless infrastructure training for new staff (2 days at $1800 per day)	$3 600	1	number of days	$1 800	25920	12960
		14			**672408**	**129742**
Rate: $1 = R7.2						

PROJECT NAME: WW-P007-03						
	cost	changes	nature of changes	cost of change	Original costs	costs of change
Design and Planning Costs						
consulting	$3 600	1		$20	27360	152
RF design (802.11a)	$3 000				22800	0
Infrastructure design	$3 000				22800	0
Project management					0	0
					0	0
Network Infrastructer					0	0
Infrastructure Installation (2 days labour at $1,250 per day)	$2 500	2		$2 500	19000	19000
Infrastructure Cabling	$1 500				11400	0
Infrastructure Hardware(Appr. 4 new POE switches)	$10 000	4	rising costs		76000	0
					0	0
Wireless Hardware					0	0
Aps(20 Aps at $50 each)	$1 000				7600	0
Controllers (2 at					0	0
					0	0
Wireless Installation					0	0
Installation (4 days labour at $1,125per day)	$4 500	2		$2 250	34200	17100
User training (2 days labour at $1,150per day)	$2 300	1		$1 150	17480	8740
Go live support (1 day labour at $1.200 PER DAY)	$1 200				9120	0
Wireless Certification	$3 000				22800	0
					0	0
Management and Integration					0	0
Management tool Installation (1 days at $1,800)	$1 800	1		$1 800	13680	13680
Intergrated wireless into existing network manegement tool(2 days labour at $1250 per day)	$2 500	2		$2 500	19000	19000
Wireless infrastructure training for new staff (2 days at $1800 per day)	$1 800	**13**			13680	0
					316920	**77672**
Rate: $1 = R 7.6						

PROJECT NAME: WW-P007-05						
	cost	changes	nuture of changes	cost of change	Costs of change	
Design and Planning Costs						
consulting	$3 128	1		($128)	23147	-947
RF design (802.11a)	$2 850				21090	0
Infrastructure design	$2 250				16650	0
Project management	$2 500				18500	0
					0	0
Network Infrastructer					0	0
Infrastructure Installation (2 days labour at $1,525 per day)	$3 500	2		$2 500	25900	18500
Infrastructure Cabling (1 day at $1 500)	$1 500				11100	0
Infrastructure Hardware(Appr. 6 new POE switches at $1 120 each)	$6 720	4	rising costs		49728	0
					0	0
Wireless Hardware					0	0
Aps(120 Aps at $65 each)	$7 800				57720	0
Controllers (9 Allied Telesyn AT-FS750-24 PORT AT $450)	$4 050				29970	0
					0	0
Wireless Installation					0	0
Installation (7 days labour at $1,150 per day)	$8 050	3		$3 450	59570	25530
User training (2 days labour at $1,200per day)	$2 400				17760	0
Go live support (1 day labour at $1.200 per day)	$1 200				8880	0
Wireless Certification	$2 500				18500	0
					0	0
Management and Integration					0	0
Management tool Installation (3 days at $990)	$3 070	1		$990	22718	7326
Integrated wireless into existing network manegement tool(3 days labour at $ 900 per day)	$2 700	2		$1 800	19980	13320
Wireless infrastructure training for new staff (1 day at $1000 per day)	$1 000	**13**			7400	0
					408613	**63729**
Rate: $1 = R 7.4						

PROJECT NAME: WW-P008-06						
	cost	changes	nature of changes	cost of change	Costs of change	
Design and Planning Costs						
consulting	$2 500	1		($45)	19750	**-356**
RF design (802.11a)	$2 500				19750	**0**
Infrastructure design	$3 500				27650	**0**
Project management	$2 500				19750	**0**
					0	**0**
Network Infrastructure					0	**0**
Infrastructure Installation (3 days labour at $1,155 per day)	$3 465				27374	**0**
Infrastructure Cabling (1 day at $ 950)	$950				7505	**0**
Infrastructure Hardware(Appr. 3 new POE switches at $432 each)	$1 296				10238	**0**
					0	**0**
Wireless Hardware					0	**0**
Aps(50 Aps at $50 each)	$2 500				19750	**0**
Controllers (2 Allied Telesyn AT-FS750-24 PORT AT $544)	$1 088				8595	**0**
					0	**0**
Wireless Installation					0	**0**
Installation (4 days labour at $1,125 per day)	$4 500	1		$1 125	35550	**8888**
User training (2 days labour at $1,200per day)	$2 400				18960	**0**
Go live support (1 day labour at $1.200 per day)	$1 200				9480	**0**
Wireless Certification	$2 500				19750	**0**
					0	**0**
Management and Integration					0	**0**
Management tool Installation (2 days at $1 255)	$2 510	1		$1 255	19829	**9915**
Integrated wireless into existing network manegement tool(3 days labour at $ 950 per day)	$2 850	2		$1 900	22515	**15010**
Wireless infrastructure training for new staff (2 days at $1000 per day)	$2 000	**5**			15800	**0**
					302246	**33457**
Rate: $1 = R 7.9						

PROJECT NAME: WW-P008-09						
	cost	changes	nuture of changes	cost of change	original co	cost of c
Design and Planning Costs						
consulting	$1 500	1	revised quote	$50	11850	395
RF design (802.11a)	$2 500				19750	0
Infrastructure design	$1 750				13825	0
Project management	$2 500				19750	0
					0	0
Network Infrastructure					0	0
Infrastructure Installation (3 days labour at $850 per day)	$2 450				19355	0
Infrastructure Cabling (1 day at $ 1100)	$1 100				8690	0
Infrastructure Hardware(Appr. 3 new POE switches at $350 each)	$1 750				13825	0
					0	0
Wireless Hardware					0	0
Aps(30 Aps at $45 each)	$1 350				10665	0
Controllers (2 Allied Telesyn AT-FS750-24 PORT AT $520)	$1 040				8216	0
					0	0
Wireless Installation					0	0
Installation (2 days labour at $876 per day)	$1 752	1	additional day	$876	13841	6920
User training (2 days labour at $580 per day)	$1 160				9164	0
Go live support (1 day labour at $500 per day)	$500				3950	0
Wireless Certification	$1 700				13430	0
					0	0
Management and Integration					0	0
Management tool Installation (1 days at $560)	$560	1	additional day	$560	4424	4424
Integrated wireless into existing network manegement tool (1 day labour at $ 560 per day)	$2 240	1	additional day	$560	17696	4424
Wireless infrastructure training for new staff (2 days at $480 per day)	$960	4			7584	0
					196015	**16163**
Rate: $1 = 7.9						

PROJECT NAME: WW-P008-12						
	cost	changes	nuture of changes	cost of change	original c	costs of c
Design and Planning Costs						
consulting	$2 500	1	revised quote	$50	19750	420
RF design (802.11a)	$3 000				23700	0
Infrastructure design	$1 750				13825	0
Project management	$3 500				27650	0
					0	0
Network Infrastructure					0	0
Infrastructure Installation (5 days labour at $650 per day)	$3 250				25675	0
Infrastructure Cabling (1 day at $ 1100)	$1 100				8690	0
Infrastructure Hardware(Appr. 35new POE switches at $340 each)	$10 820				85478	0
					0	0
Wireless Hardware					0	0
Aps(155 Aps at $50 each)	$7 750				61225	0
Controllers (10 Allied Telesyn AT-FS750-24 PORT AT $520)	$5 200				41080	0
					0	0
Wireless Installation					0	0
Installation (10 days labour at $876 per day)	$8 760	2	additional days	$1 752	69204	14717
User training (2 days labour at $580 per day)	$1 160				9164	0
Go live support (1 day labour at $500 per day)	$500				3950	0
Wireless Certification	$1 600				12640	0
					0	0
Management and Integration					0	0
Management tool Installation (3 days at $560)	$1 680	1	additional day	$560	13272	4704
Integrated wireless into existing network manegement tool(3 day labour at $ 850 per day)	$2 550	2	additional days	$1 700	20145	14280
Wireless infrastructure training for new staff (2 days at $480 per day)	$960	6			7584	0
					443032	**34121**
	Rate: $1 =R 7.9			**Rate: $1 = R 8.4**		

PROJECT NAME: WW-P008-22						
	cost	changes	nature of changes	cost of change	original c	cost of c
Design and Planning Costs						
consulting	$1 200	1	revised quote	$50	9360	430
RF design (802.11a)	$2 200				17160	0
Infrastructure design	$1 150				8970	0
Project management	$1 500				11700	0
					0	0
Network Infrastructure					0	0
Infrastructure Installation (4 days labour at $820 per day)	$3 280	1	1 additional day	$820	25584	7052
Infrastructure Cabling (1 day at $ 1100)	$1 100				8580	0
Infrastructure Hardware(Appr. 3 new POE switches at $426 each)	$1 278				9968	0
					0	0
Wireless Hardware					0	0
Aps(40 Linksys at $126 each)	$5 040	1	weak rand 7.8 to 8.6		39312	4032
Controllers (2 Allied Telesyn AT-FS750-24 PORT AT $448 each)	$896				6989	0
					0	0
Wireless Installation					0	0
Installation (5 days labour at $940 per day)	$4 700				36660	0
User training (2 days labour at $580 per day)	$1 160				9048	0
Go live support (1 day labour at $500 per day)	$500				3900	0
Wireless Certification	$2 300				17940	0
					0	0
Management and Integration					0	0
Management tool Installation (3 days at $832)	$2 496	1	additional day	$832	19469	7155
Integrated wireless into existing network management tool (2 days labour at $ 850 per day)	$1 700	2	additional days	$1 700	13260	14620
Wireless infrastructure training for new staff (2 days at $480 per day)	$960	**6**			7488	0
					245388	**33289**
	Rate:$1=7.8			**Rate: $1 = R 8.6**		

PROJECT NAME: WW-P008-12						
	cost	changes	nature of changes	cost of change	original c	costs of c
Design and Planning Costs						
consulting	$2 500	1	revised quote	$50	19750	420
RF design (802.11a)	$3 000				23700	0
Infrastructure design	$1 750				13825	0
Project management	$3 500				27650	0
					0	0
Network Infrastructure					0	0
Infrastructure Installation (5 days labour at $650 per day)	$3 250				25675	0
Infrastructure Cabling (1 day at $ 1100)	$1 100				8690	0
Infrastructure Hardware(Appr. 35new POE switches at $340 each)	$10 820				85478	0
					0	0
Wireless Hardware					0	0
Aps(155 Aps at $50 each)	$7 750				61225	0
Controllers (10 Allied Telesyn AT-FS750-24 PORT AT $520)	$5 200				41080	0
					0	0
Wireless Installation					0	0
Installation (10 days labour at $876 per day)	$8 760	2	additional days	$1 752	69204	14717
User training (2 days labour at $580 per day)	$1 160				9164	0
Go live support (1 day labour at $500 per day)	$500				3950	0
Wireless Certification	$1 600				12640	0
					0	0
Management and Integration					0	0
Management tool Installation (3 days at $560)	$1 680	1	additional day	$560	13272	4704
Integrated wireless into existing network manegement tool(3 day labour at $ 850 per day)	$2 550	2	additional days	$1 700	20145	14280
Wireless infrastructure training for new staff (2 days at $480 per day)	$960	6			7584	0
					443032	**34121**
	Rate: $1 =R 7.9			**Rate: $1 = R 8.4**		

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1. Sibanda K, Muyingi H. And Mpofu N. Closing the Digital Divide: Towards wireless technology architecture for rural connectivity. Proceedings of ICT Africa, NEPAD Conference 2008, Ethiopia.

2. Sibanda K, Muyingi H.N. Emerging Wireless Technologies a Panacea for Closing the Digital Divide in Developing Countries. SACLA proceedings 2007 ISBN IS 978-0-7974-3466-0.

3. Mabanza N. and Sibanda K. Using Wireless Technologies for Delivering ICT services to Rural Communities of Africa. UNECA Conference, ADDIS ABABA, 2008.

4. Sibanda K, Muyingi H.N and Mpofu N. Bandwidth Provisioning across Multiple Administrative Domains in multiple Differentiated Service Networks. SACLA proceedings 2007. ISBN IS 978-0-7974-3466-0

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Journal Papers under Review

1. Sibanda K. Sustainability of Low Cost Rural Broadband Networks: Beyond Experimental Phase, with South African Computer Journal

2. Sibanda K. Enhancing wireless network deployment cost estimation using the Poisson process: The Probabilistic Cost Model (PCM), with The Electronic Journal of Information Systems in Developing Countries (EJISDC)

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