CHALMERS | GÖTEBORG UNIVERSITY

MASTER'S THESIS

3G Infrastructure Sales Forecasting

A Causal Modeling Approach

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Abstract

This document presents a model to forecast WCDMA infrastructure equipments sales. The model was ordered by the company Ericsson AB with the main purpose that the model's outputs would help the organization in the creation of its long-range forecasts and support its decision makers. A forecasting software tool was developed as an implementation of this model and it enables the users to simulate different scenarios, in order to help answering WHAT-IF questions and conducting sensitivity analyses.

Technology forecasting is much like forecasting the weather; it is subject to nonlinearities and small errors that are not significant in the short term but can become very large over five years. Frequently, trend analyses are not so useful and rarely describe the real world in technology predicting. All these aspects together with the fact that there is no historical data for the subject of our forecast (specially due to the novelty of WCDMA technology), were the main drivers of our choice for a causal modeling approach.

One of the strengths of the tool is that, being a simulation instrument, it allows for analysis and comprehension. This is mainly a consequence of our modeling approach. Causal models are considered a tool conductive to support thinking, group discussion and learning in management teams.

Our intention with this document is that you must neither have specific telecommunications market information or specific technology knowledge in order to understand and learn from our conclusions. The approach to modeling presented here can be applied on other market sectors, specially when no historical data is available.

Acknowledgments

We would really like to thank all people at Ericsson that we have contacted during all these hard-working months. We thank them for sharing their valuable time and knowledge with us.

We are very grateful for all the valuable insights, suggestions, comments, and contributions from Fredrik Gessler and Svante Bergqvist, respectively, the coach and the orderer of our project. They supported us during all this work and had patience when our modeling seemed to take forever. Their assistance was vital for the research.

We would also like to thank Anette Borg and Mats Ek from Ericsson's Systems and Technology group for all their valuable feedback and support on all phases of our project. Much of our progress was due to Anette's ability to understand our ideas and to push us into the right track, turning what were just thoughts into achievable results.

We would sincerely like to thank Birgitta Olin, from Ericsson Research. Without her help we would probably still be working with ways to correlate coverage area measures with capacity measures.

Finally, we would like to thank Patrik Albin, our supervisor at Chalmers for always encouraging and cheering us up, not only during this thesis work, but during most part of our Master Course; as well as Ivar Gustafsson, our programme director, who gave us the opportunity to pursue our studies in Sweden.

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1 Introduction

This chapter starts with information about the project orderer and is followed by the purpose of the project. The background and context of this Master's Thesis is discussed. You will also get an overview of the problem treated here and a description of project scope.

1.1 Project Orderer

Company: Ericsson AB (Kista, Sweden)

Department: Business Unit Access (BUAC) - WCDMA Product Area

Ericsson is a worldwide provider of telecommunications equipment and related services to mobile and fixed network operators. Over 1,000 networks in 140 countries utilize Ericsson's network equipments and 40 percent of all mobile calls are made through their systems.

Ericsson is one of the few companies worldwide that can offer end-to-end solutions for all major mobile communications standards, including the 3G (Third Generation) wireless network technology WCDMA (Wideband Code Division Multiple Access).

Business Unit Access' main role is to secure Ericsson's global leadership in second and third generation radio access networks. Its responsibility covers a wide spectrum of activities, from product development to customer delivery.

This Master of Science project has been conducted on behalf of Ericsson's BUAC, within the WCDMA Product Area. The main role of the WCDMA Product Area is to develop and maintain a competitive, high-quality product portfolio for WCDMA Radio Access Network maximizing long term profitable growth.

1.2 Purpose Of The Project

The main purpose of the project was to develop a forecasting model that is able to quantify the WCDMA's market size and translate it into reliable forecasts of WCDMA infrastructure sales. It was also part of our assignment to design a software tool as an implementation of the forecasting model.

The primary goal of the tool is to quantify qualitative assumptions regarding future capacity expansions for the already deployed WCDMA networks. This means that the tool is able to capture how the input parameters determine the capacity expansions of the actual WCDMA networks and how these effects can be translated into the amount of equipments needed to cover that capacity demand.

1.3 Background And Context

Many sales forecasting techniques are based upon some form of extrapolation of curves fitted to historical data. They are referred to as exploratory/descriptive forecasting methods, and are used to project future developments on the basis of past history (Armstrong 1999). The implicit assumption in the use of these techniques is that what has happened in the past provides a powerful indication of what will occur in the future. In essence, they start with a set of events that have taken place up to the time of forecast, an attempt to identify the patterns present in that history, and project these patterns into the future. They assume that whatever has caused the patterns of the past, will continue operating to produce similar patterns in the future (LGA 2001).

However, in order to take advantage of these methods, two things are necessary. Firstly, one needs to have relevant and reliable historical data systematically collected (Armstrong 1999). Secondly, one needs to know which shape of curve to fit to the data. The latter is less of a problem, as there are well established patterns which can be used by the forecaster.

The problems in quantifying the market size of new products or services in high technology businesses lie in the fact that there might not exist enough data to calibrate a classical forecasting model (Lynn *et al.* 1999). In this paper we introduce an alternative way of reaching medium to long-range sales forecasts for certain types of infrastructure equipments belonging to radio base stations from WCDMA mobile networks.

Specially due to the novelty of WCDMA technology, historical data relating to infrastructure sales performance can be either rather short or not available. Besides that, while analyzing the growth of mobile network services' demand and the corresponding capacity requirements, past sales history may fail to capture some of the new key drivers of network expansions and new changing factors that may appear. Thus, in order to improve our estimates, our approach takes into account new technologies and applications, new patterns of usage of the network resources and desired grade of service. That means, we "combine history of telecommunications and its technological, structural and service development, with an understanding of how shocks to this system could change the developmental pathways"(Tumolillo 2004).

1.4 Project Scope Description

This document presents a forecasting model for WCDMA infrastructure equipments sales that is based on the market dynamics simulation. The key market drivers and influencing factors for capacity expansions of the WCDMA networks are analyzed and modeled.

A forecasting software tool was developed as an implementation of this model and was designed to be used for management purposes in the Ericsson organization's dimensioning and products development.

Ericsson has requested that the end-user interface of the tool should be based on the Microsoft Excel software. Thus, the model has been implemented with the VBA (Visual Basic For Applications) programming language, since it is fully integrated and automatically available when installing the Microsoft Office package.

The tool receives inputs related to the operators' strategy, as well as other inputs related to their network's traffic, country characteristics and demography, and will produce yearly estimates of required infrastructure equipments.

The outputs are presented at an operator level, both for the entire market and limited to Ericsson's deliveries, i.e., the amount of equipments required worldwide and those that will be bought from Ericsson. The time frame of the output is five years ahead in time on an yearly basis.

2 General Investigation Of The Problem

This chapter sets the goals of this study. The problem definition is given; the project scope and delimitations are better discussed and the choice of the method is justified.

2.1 Problem Definition

The objective of the project is to develop a forecasting model that provides reliable sales estimates of infrastructure equipments (radio base stations and its related components) for WCDMA mobile networks in a five years time frame, both from a worldwide perspective and limited to Ericsson's market share. A forecasting software tool must be developed as an implementation of the model.

Our investigation moves forward from another sort of WCDMA Forecasting model developed in 2004 (Gustavsson and Nilsson 2004), hereinafter referred to as *Coverage Model*.

The main objective of the Coverage Model is to determine how the operators will initially deploy their WCDMA networks. In other words, it estimates how many base stations will be sold to each of the operators to support their initial network deployment phase or roll-out phase. The main input parameter of this model is the percentage of the population that an operator intends to cover (coverage ambitions) or the corresponding regulatory coverage requirements. The model also takes into account if an operator has a 2G (Second Generation) GSM wireless network already deployed and will be upgrading toward a WCDMA network, since this may affect the amount of new WCDMA radio base stations that will be deployed.

From a network capacity perspective, it will take some time (months or even years) for the operators to start facing the needs for expanding their networks after their initial deployment. The initial number of subscribers and the amount of traffic generated by each subscriber may be very low. However, considering the wide range of new mobile services provided by the WCDMA technology, it is expected that the network traffic will increase substantially in all markets, forcing the operators to upgrade the capacity of their current infrastructure. This is when our model start acting, determining the needs for future capacity expansions of the radio base stations. This model will be simply referred as the *Capacity Model* through this document. Figure 2.1 depicts a simplified framework of our model.

Since Ericsson must quantify the entire market size for the technology, then we must produce sales estimates of the number of radio base stations and its components, both from the coverage and the capacity perspective. Therefore, one model will be complementing the other. The Coverage Model estimates the number of base stations for the initial roll-out phase, constrained by population coverage requirements, and the Capacity Model determines if extra radio base stations are needed or if the current radio base station components require expansions in order to support the increased network traffic.

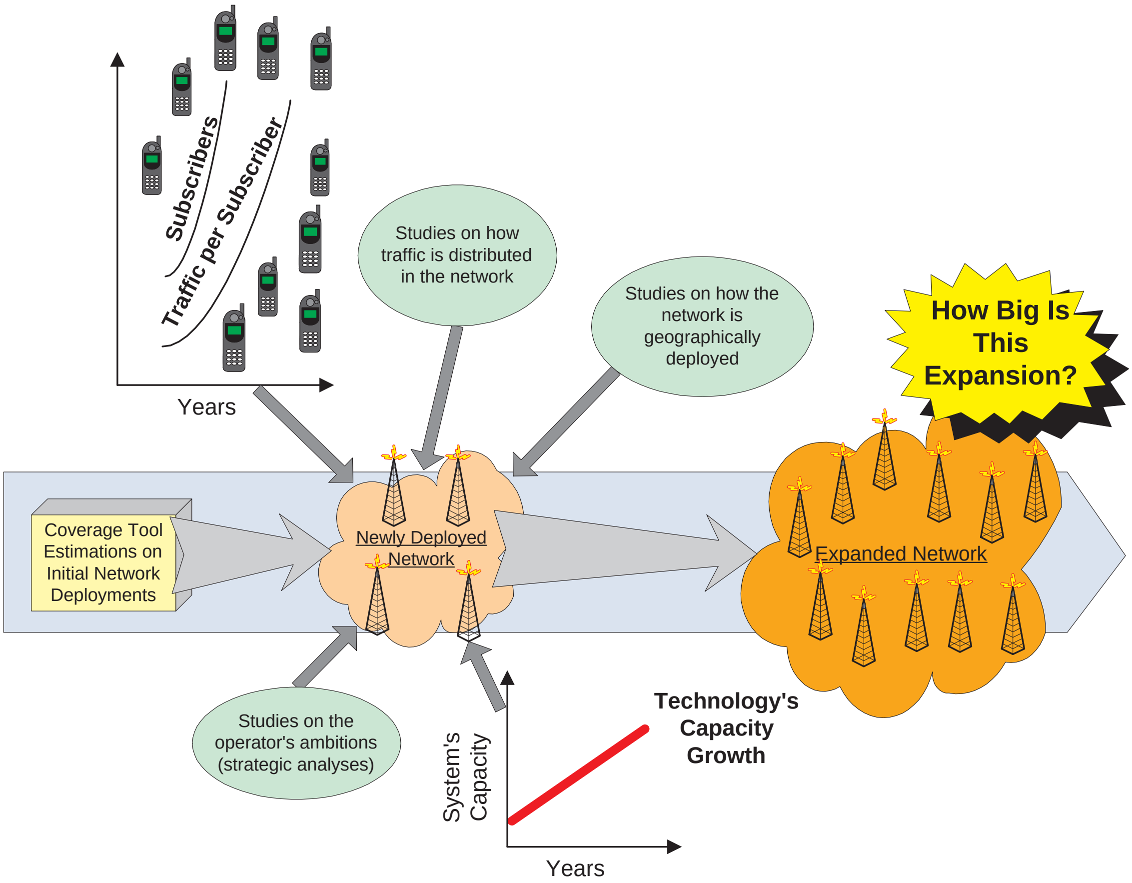

Figure 2.1. Our model's simplified framework

2.2 Scope And Delimitations

The forecasting tool developed is an implementation of a model that combines parameters that are assumed to affect the deployment of capacity expansions in WCDMA networks into a simulation of how these parameters impact the network's performance.

There is a huge complexity in building a forecasting model that estimates the market size, since there are too many parameters that drive the process. Some parameters are difficult to model and to integrate into one model, thus several assumptions and simplifications have to be made in order to reduce the complexity and therefore, making it possible for its users to understand the logic and process behind it.

We focused on developing a forecasting model comprehensive enough to identify the truly causal factors, but simple enough to explain to those who will need to make decisions based on it. The model is implemented as a quantification tool that takes different assumptions and forecasts as input, which requires the user to have information about the possible future scenarios and insights about the operators' strategies.

The granularity of the model's input parameters may range from individual operators in a country, to inputs by the whole country or region. The output will be given in the granularity level defined by the input, year by year. This means that in case the inputs are given by the whole country, the outputs will also be given for the whole country.

Some of the inputs are forecasts from a different nature and are not estimated by this model. They are supplied by different information sources. Examples of these estimates are:

- **WCDMA subscribers forecast** - estimates of the number of subscribers in a specific operator's network, now and in the future.
- **Bit rate ambitions** - estimates of what is the desired grade of service that the operators would like to offer to their customers, in terms of packet data transfer speeds, both for the uplink and downlink.
- **Installed WCDMA base (number of Radio Base Stations - RBSs)** - e.g. What is going to be the network layout (in terms of number of RBSs) in the future? What is the number of RBSs that should have the performance checked in order to say that they require capacity expansions?
- **Monthly traffic forecasts per subscriber** - estimates of the average number of minutes of network use (audio and video) and the average data packet traffic.

A detailed description of all inputs is found in Chapter 7.

2.3 Choice Of The Model

One important project requirement was that the model should enable the user to simulate different scenarios. For instance, how would an increase in the number of subscribers or in the traffic per subscriber impact the deployment of capacity expansions in the network? This model's capability is deemed important, since scenario analysis can be a way to handle the uncertainties of the future and to gain flexibility.

It was requested that the model should be easy to understand and the output values should be easy to justify. The causality between inputs and outputs should be clear and the model should not operate as a "black box", with hidden parameters and computations.

Allowing the users of the forecasting tool to understand the logic behind the model and explaining how to interfere in this process will satisfy this criteria of simplicity and will enable the decision makers to accurately judge the trustworthiness of the model's outputs.

Driven by the requirements above, we have chosen a causal modeling approach to solve our problem. A causal model enables an understanding of the factors which drive the progress of the process to be studied. A theoretical causal model is based on the premise that if all influencing factors can be identified, and their inter-actions defined and quantified, it should be possible to develop a forecasting model that gives highly accurate estimates. In addition, this approach to modeling provides a clear opportunity to handle scenario analysis and to explicitly represent how the outputs relate to the inputs.

2.4 Thesis Structure

The structure of this document and the thesis outline are presented below.

Chapter 3 - Overview Of The Project Phases

This chapter describes how we could reach the goal of this project. During the work of developing the model and implementing it, we proceeded through some major phases, consisting of different tasks. We discuss how these tasks were accomplished. The chapter ends with a discussion of the method used.

Chapter 4 - Causal Modeling Overview

Here you get information about causal modeling. The chapter begins with an overall depiction of what is a causal model, followed by some examples of how intuitive (but rather complex) causal models can be. The chapter ends by discussing the sources of error in causal modeling.

Chapter 5 - Mobile Communications Overview

This chapter supplies you with basic information about the Mobile Communications Systems in order to be able to understand what exactly is being simulated by the forecasting tool. The contents of this chapter are essential to those that are not familiar with basic knowledge on what composes a radio base station and radio network planning (including alternatives for networks' capacity expansions). The theory presented here will be needed to understand the logic behind our forecasting model.

Chapter 6 - Forecasting Tool Model

This chapter briefly describes the model that is implemented in the forecasting tool. The overall reasoning behind the parts of the model as well as how they interconnect is described here. The chapter begins with an overview of the model followed by an initial discussion on expansions deployments dimensioning and descriptions of how the different aspects of confronting forecasted network demand with forecasted network capacity have been dealt with. The chapter ends by describing the assumptions that are made in this model. The detailed algorithm is presented in the Detailed Model Specification chapter.

Chapter 7 - Detailed Model Specification

Here we set the bounds for the system. Both the tools and supplies that support the tool are better described here. The logic behind the model is presented by means of flowcharts of the algorithm. Here you will get detailed descriptions.

Chapter 8 - Forecasting Tool

This chapter presents the WCDMA Forecasting Tool. Here you will get an insight of the tool's structure, design and layout.

Chapter 9 - Case Study: Greenfield Versus Incumbent Operators

We have analyzed differences in capacity expansions deployments between Greenfield and Incumbent operators with the help of our tool. The purpose of this analysis is to show that simple reasoning and assumptions can be translated to numbers by using the tool.

We have tested a hypothesis and its validity is presented by means of two results.

Chapter 10 - Case Study: Greenfield Versus Incumbent Operators

We have analyzed differences in capacity expansions deployments between Greenfield and Incumbent operators with the help of our tool. The purpose of this analysis is to show that simple reasoning and assumptions can be translated to numbers by using the tool. We have tested a hypothesis and its validity is presented by means of two results.

Chapter 11 - Analysis And Discussion

The model developed in this project is discussed here in terms of its reliability, validity and relevance. The strengths and weaknesses of the tool are also analyzed and discussed.

Chapter 12 - Conclusions

This chapter summarizes the discussions in the Analysis and Discussion chapter. Here we access the validity of our results and comment on their significance. Our main findings and conclusions are also presented here.

Chapter 13 - Further Research

This chapter describes the areas of relevant further research as well as the possibilities for improvements we have found along the project path.

3 Overview Of The Project Phases

This chapter describes how we could reach the goal of this project. During the work of developing the model and implementing it, we proceeded through some major phases, consisting of different tasks. We discuss how these tasks were accomplished. The chapter ends with a discussion of the method used.

3.1 Overview

In this project we have proceeded through eight major phases: Studies in WCDMA; Selection of most important parameters; Primary Analysis - Studies in forecasting methodologies; First candidate model development; Selection of most important parameters; Secondary Analysis - Studies in auxiliary tools and data; Second candidate model development; Forecasting Tool implementation. The most time-consuming phases were the selection of most important parameters, Primary Analysis - Studies in forecasting methodologies and First candidate model development.

Figure 3.1 shows how the different phases connect to each other. These phases were not as sequential as it might seem in the figure, but often overlapped. We often had to proceed through two or three phases at the same time in order to reach a specific goal.

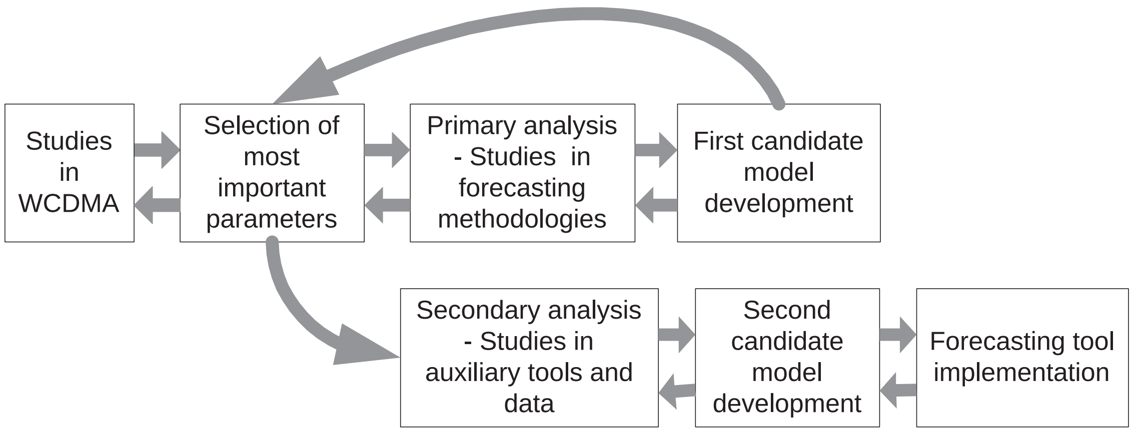

Figure 3.1. Project phases overview

3.2 Studies In WCDMA

Our object of study was the WCDMA technology, thus we started our research performing a deep study on the relevant aspects of the technology. Our assignment was to make forecasts of infrastructure equipments sales, we have then focused on getting a better understanding about these equipments.

Much of this information was gathered by studying reports written by Ericsson's employees. Books in WCDMA theory were also consulted, since we had to identify the key WCDMA parameters that should be considered in our analysis or that could affect our forecasts.

3.3 Selection Of Most Important Parameters

In order to define the parameters that affect how many equipments will be sold, we analyzed information gathered from both reports, meetings and interviews[1]. All the people we met and/or interviewed were employees at Ericsson with good knowledge about a specific topic of interest.

This information gathering phase led us to a very large set of potential model parameters, not only intrinsic to the technology, but also from an economical perspective. We had then to analyze which parameters have greater impact on WCDMA infrastructure sales.

3.4 Primary Analysis - Studies In Forecasting Methodologies

At this phase, we tried to identify as many methodologies as possible that could help us with our task of developing a sales forecasting model to a market with no significant historical sales data available. When we eventually got a better perception of our requirements and goals, most of the methodologies studied were discarded. We realized that there was no immediate methodology that could be directly applied to solve our problem, so we decided to develop our own methodology and model.

We also performed an intensive study in other forecasting models developed at Ericsson. Each model was was deeply analyzed in an attempt to identify its strengths and weaknesses, that were later considered when we started developing our own model.

3.5 First Candidate Model Development

This was an important phase in our project development. One first candidate model was developed and seminars and presentations inside Ericsson were arranged by us. From these meetings we could receive a lot of helpful and important feedback from Ericsson's employees. These results were taken into consideration and a completely new version of the model was later developed.

3.6 Selection Of Most Important Parameters

This was a secondary phase for selection of most important parameters. Extra requirements were placed on our project and we then perceived a need for searching for more information and selecting new key model parameters. The new set of parameters and

[1]The meetings and interviews are listed in Appendix C - Information Resources

information gathered has led us to a new need: analyze the new sources of data and auxiliary software tools developed at Ericsson discovered during this phase.

3.7 Secondary Analysis - Studies In Auxiliary Tools And Data

The next step was to analyze new sources of data and auxiliary software tools that were discovered during the last phase and that could be used in our model. For instance, we have decided that some of the inputs to our model should come from other tools developed at Ericsson.

Intensive tests and validation procedures were performed on the auxiliary tool's outputs. At this stage we started prototyping the algorithms that would be handling the new data sources.

It was deemed important to better understand these new information sources, as this could help us increasing the accuracy in our final results. To this purpose, we have held interviews with Ericsson's employees in order to discuss all the results of our analyses of these new data sources.

3.8 Second Candidate Model Development

After gathering enough information about our problem and having identified the key parameters, we realized that it was important to create an annotated visual representation showing the key factors and their relationship. Then we developed an intuitive causal influence diagram of the model.

The forecasting model based on that approach was approved and was later implemented as a forecasting tool software.

3.9 Forecasting Tool Implementation

It was also a requirement that the end-user interface of the forecasting software tool should be based in Microsoft Excel and therefore, Visual Basic for Applications (VBA) was chosen as the programming language. The approved forecasting model was then implemented as an Excel-based software tool.

The model was continuously adjusted and calibrated during the forecasting tool implementation phase in order to fulfill former and new requirements put by Ericsson.

3.10 Initial Discussion On The Project

As discussed in Section 3.1, the sequential representation of the project phases should in fact consider some overlapping phases. Even though we have followed more an iterated process, this sequential figure is a good representation for the milestones that we had to reach during our progress. These milestones included identification of key parameters, selection of a model and final implementation. By defining these milestones, often accompanied by project deliverables, we could keep the work on schedule.

The final model was developed following a causal modeling approach to forecasting. Developing a causal influence diagram has enabled us to understand the relationship between the key parameters that affect sales performance. Causal influence diagramming is a kind of mapping concept, especially tailored for dynamic and complex domains, as in our case, where there is a high number of parameters and influencing factors driving the process. Chapter 4 presents an overview of causal modeling and our causal influence diagram.

A causal approach to modeling may be applied to other market sectors, specially when no historical data is available. However, one thing to bear in mind is that the crucial and most time-consuming task while developing a causal model is to study and understand the complex system you want to mimic the dynamics. On one hand you can apply causal models in any forecasting problem, but on the other, the reliability of your results are deeply connected to your ability to model all major driving forces. This is an important issue that was dealt with during all phases of our work and was certainly our biggest challenge.

4 Causal Modeling Overview

Here you get information about causal modeling. The chapter begins with an overall depiction of what is a causal model, followed by some examples of how intuitive (but rather complex) causal models can be. The chapter ends by discussing the sources of error in causal modeling.

4.1 The Causal Model

The causal model is so called because it employs cause-effect relationships between the subject of the forecast and the factors affecting it. The model does not only depict forecast over time or for a particular point of time but presents the estimation in relation to a set of circumstances. While the trend extrapolation methods (descriptive methods) assume that time reflects all factors (Gordon 1994), the causal method seeks to explain, by means of defining which variable depends on the other, the apparent relationship between the forecasted phenomenon and its influencing factors. By analyzing past data, two or three critical factors that have the most profound effect can be selected and the effect of the selected factors quantified and expressed in the form of mathematical equations. To make predictions for future years, the likely state of each selected critical factor at that point of time has to be first assessed.

This method involves mathematical equations to express the relationships and inter-relationships between variables. Moreover, its reliability strongly depends on forecasts for the selected critical factors. It tells us what the forecast is likely to be in a given set of circumstances and therefore, the likelihood of the estimation depends on if those set of circumstances will prevail in the years under forecast.

Causal models are traditionally built for strategic forecasting (long-term), whereas extrapolative/descriptive techniques are used for tactical and operational forecasting (short and medium term).

Both approaches use the same 3-step process: pattern recognition, estimation, and pattern projection. In the case of extrapolative techniques, no other variables other than the data at hand are used to predict the future. Only captured historical patterns recognized in a series of numbers are used to project future values. In contrast, causal models take into account values for independent variables. The objective here is to capture and estimate the relationship between the data to be forecasted and a set of independent variables. Therefore, with a causal model, the forecast becomes dependent on the forecasted values for the independent variables. Causal models are best used to explain observed past behaviors and/or for strategic scenario analysis.

The causal model method of prediction becomes feasible if, through research, it is possible to build a model that not only describes the development of the phenomenon to be predicted, but also explains it.

The explanation can be either causal, through motive or function, or any other type of reasoning. This means that we know the dynamic invariance of change in the process going on. Usually (though not always) such invariance remains valid also in the future and thus it gives good grounds for prediction.

Causal models allow you to explain why and how a certain forecast is reached, while no intuitive explanation is possible with the use of a descriptive model. As a consequence, causal models turn out to be key points in a complex forecasting process, principally because they allow scenario and what-if analyses.

4.2 Building A Causal Model

The first step is to prepare a conceptual causal model by drawing an influence diagram. This influence diagram must identify all the forces which affect the phenomenon being investigated and how they interact between themselves. These influences may be either direct or indirect. Some may act in a positive way to enhance the likelihood of the development or in a negative direction to make it less likely.

Figure 4.1 shows a simplified diagram for our problem. Only a few factors have been considered in this analysis. Further consideration would lead to an expansion until it became a complex web of relationships to which additions could be made almost indefinitely.

Figure 4.1 is presented with the purpose of illustrating an influence diagram. The relevance of these causal factors is not discussed in this chapter.

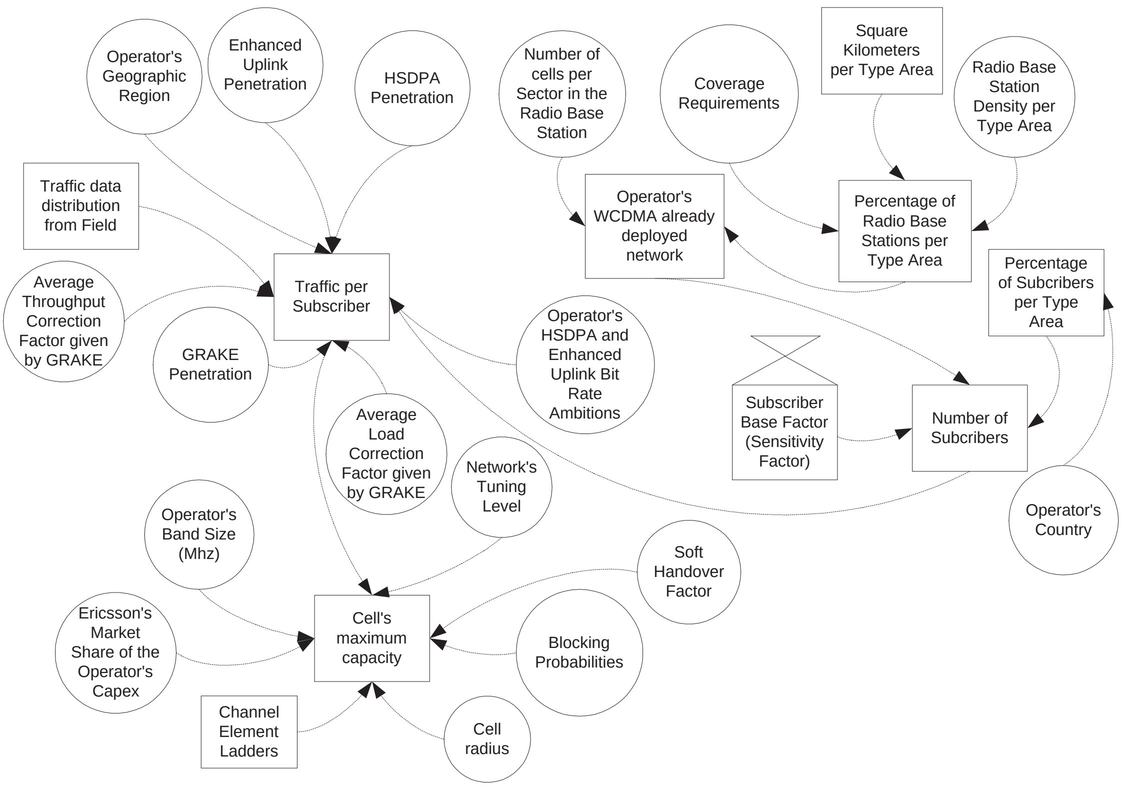

Figure 4.1. Simplified influence diagram for our problem

The second step is to develop the mathematical model. This builds upon the influence diagram by establishing the quantitative relationships linking each pair of factors. In some instances this can be done from available data.

The construction and use of a model of this type would provide a theoretically sound methodology for forecasting since it is based upon a study of all the causal factors. It explores explicitly those factors which in conjunction bring about the progress of the phenomenon being studied. It expresses the relationships in quantitative terms which can be manipulated mathematically. Thus, it appears an attractive approach. The problems arise when one attempts to apply it in practice. The most important of these are (Twiss 1992):

- the implicit assumption that the influence diagram does not change with time; new factors may emerge or some which may have been discarded as minor may become important;
- the complexity of the model if it is to be comprehensive;
- the changes which occur in some of the quantitative relationships over time;
- the impossibility of expressing some of the factors in quantitative terms;
- the inability to establish quantitative relationships between some pairs of factors;
- the investment of resources required to construct and use the model.

In case the causal model cannot be applied in practice it is necessary to find some alternative method for forecasting. Most of the practical techniques, the ones described here as descriptive, study the behavior of the phenomenon being considered over a period of time and use this to establish a trend which can be extended into the future. They are based on an analysis of what has actually happened rather than causal, which would be derived from an examination of the influences which bring it about. It is a study of 'what', rather than 'why'.

4.3 Causal Versus Descriptive Models

Brian C. Twiss presents in his book "Forecasting for Technologists and Engineers" (Twiss 1992) a great example on how a causal and a descriptive forecasting approach would be applied when forecasting the future movement of a boat adrift in the sea (Figure 4.2).

The aim is to forecast when it will be washed ashore. If one was attempting to construct a causal model it would first be necessary to identify what might cause a movement. This might include the tide, currents and the wind. For each of these one would then require to determine the effect of each of these forces, in itself not an easy task. However, these are not independent since the wind might, for example, blow the boat into an area where the current is stronger. These inter-relationships would also have to be built into the model. At this stage the mathematical model could be constructed. All that now remains is to forecast the changes in each of these forces during the period of interest, feed them into the model and compute the outcome.

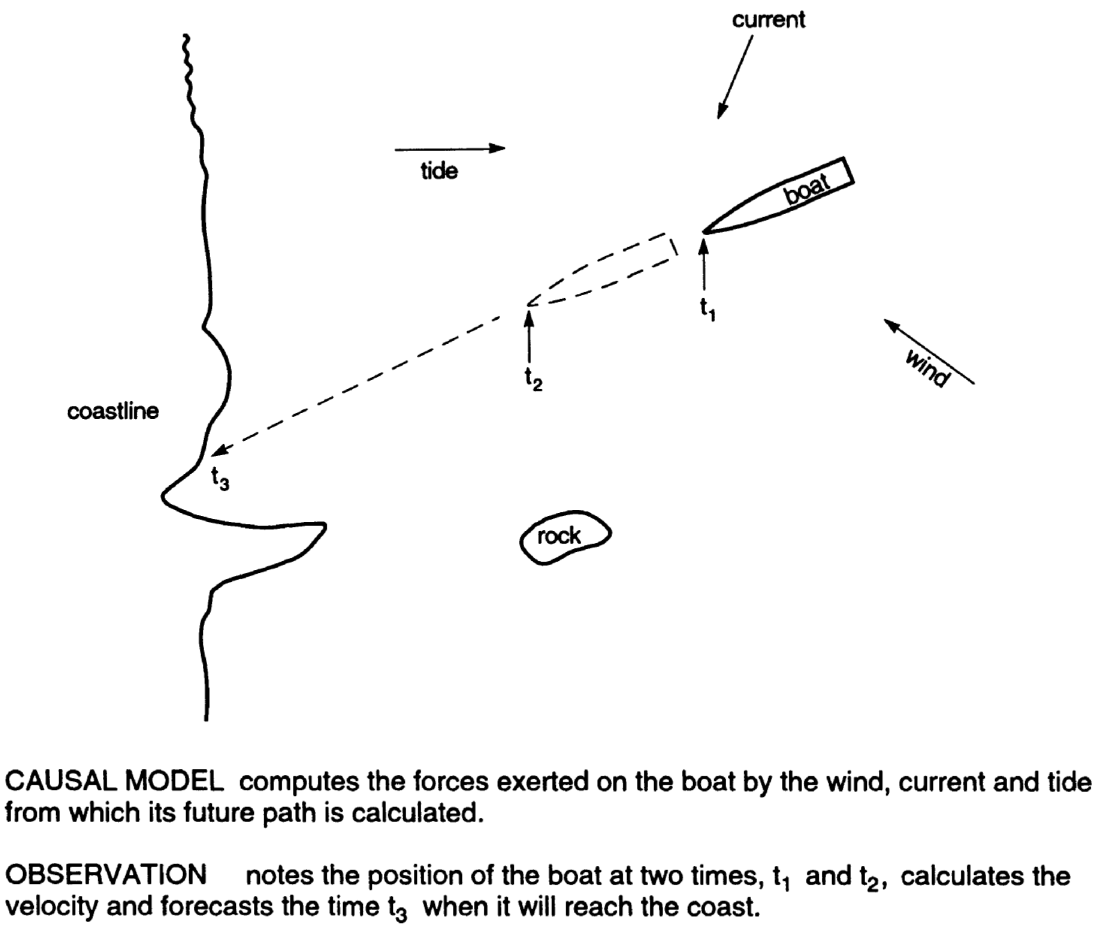

Figure 4.2. Forecasting the future movement of a boat adrift in the sea both with a causal and a descriptive approach

The alternative approach, the descriptive one, could be to note the position of the boat at two different times, compute the speed and thereby calculate when it will be driven ashore if that speed is maintained. In doing this one is assuming that all the forces acting on it remain unchanged during the whole period. Perhaps they will not.

As you can perceive, no causal factors were included in the descriptive analysis. The boat movement is mainly driven by its speed. Speed is what describes the process, the flaw is that it is assumed to be the unique driver.

4.4 Sources Of Error In Causal Modeling

Let's return to the "future movement of a boat adrift in the sea" case, described above. When following a causal modeling approach, it might also be necessary to identify hidden rocks which might impede the boat progress. The complications and expense of following this forecasting approach are evident. One might also question how accurate the forecast would be in the light of the errors that could arise at each stage. Furthermore, as Brian Twiss says (Twiss 1992), the boat might be ashore long before the forecast is completed!

Some important sources of errors in causal modeling are the ones derived from the implementation difficulties listed in Section 4.2.

4.5 Reasons For Choosing A Causal Modeling Approach

Technology forecasting is much like forecasting the weather; it is subject to nonlinearities and small errors that are not significant in the short term but can become very large over five years.

Trend analyses are not so useful and rarely describe the real world in technology predicting. Unstated so far is the fact that long-term technology forecasting is inherently flawed: Will the technology become obsolete in ten years? Product substitution effects are also often ignored in technical forecasting. In applying compound growth rates over long periods of time for forecasting we also understand that these kinds of models implicitly assume that the relationships among the variables and parameters of the model are unchanging over the period. It takes no account of changing tastes and preferences, and it assumes that demand is fixed in its dynamical aspects and nothing will deflect that, and that pricing has no impact.

By pursuing studies on the subject of our forecast and using the theory, not the data, as a guide to selecting the causal variables, it was clear that the relationships among variables in the model were so strong and dynamic, that we could not just assume them to be constant. Thus, a descriptive model was not a good option to solve our problem.

Furthermore, the fact that there is no historical data for the subject of our forecast, was another main driver of our choice for a causal modeling approach.

The model implemented in the forecasting tool is described in Chapter 6. The overall reasoning behind the parts of the model, as well as how they interconnect is described there. However, before entering in details on the model, it is important to have a basic understanding of mobile communications in general and specially of the WCDMA technology itself, which is the object of our study. This will be presented in the next chapter.

5 Mobile Communications Overview

This chapter supplies you with basic information about the Mobile Communications Systems in order to be able to understand what exactly is being simulated by the forecasting tool. The contents of this chapter are essential to those that are not familiar with basic knowledge on what composes a radio base station and radio network planning (including alternatives for networks' capacity expansions). The theory presented here will be needed to understand the logic behind our forecasting model.

5.1 Introduction

Cellular wireless communications is one of the fastest growing and most demanding telecommunications applications. Today, it represents a continuously increasing percentage of all new telephone subscriptions around the world, reaching 2.14 billion subscriptions by the end of 2005[1]. From the beginning of 2003, the number of global mobile subscribers has overtaken the global number of fixed telephony lines. It is expected that the volume of global mobile traffic will soon overtake the global fixed traffic, as shown in Figure 5.1.

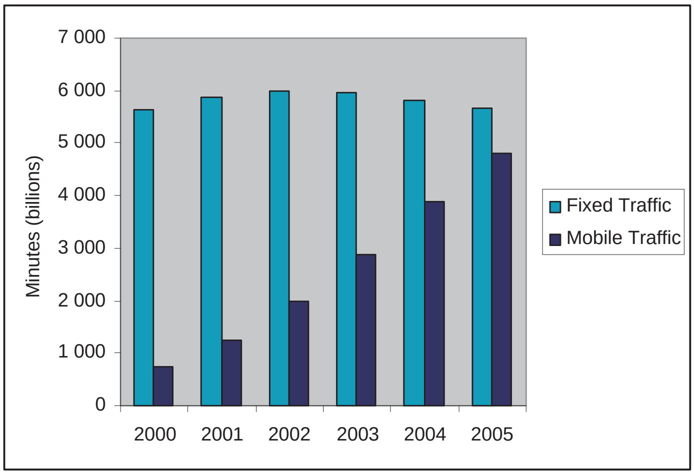

Figure 5.1. Global mobile traffic versus fixed telephony traffic, *Source: Mobile@Ovum, 2005*

Cellular wireless communication networks provide voice and data communication throughout a wide geographic area. Cellular systems divide large geographic areas into small radio areas (cells) that are interconnected with each other. Each cell coverage area has one or several transmitters and receivers that communicate with mobile telephones within its area.

GSM (Global System for Mobiles) and WCDMA (Wideband Code Division Multiple Access) are examples of second generation and third generation mobile systems, respectively.

[1] Source: Informa Telecoms and Media, 2005

5.2 Mobile Systems Evolution

There has been a phenomenal growth in wireless communications technology over the last years, with a significant increase in subscribers and an increased demand for higher data rates to support the latest multimedia applications such as music downloads, gaming and mobile TV. The broadband mobile telephony era is starting and the demand for capacity has never been so high.

3G systems offer better system capacity and higher data transmission speeds to support wireless Internet access and wireless multimedia services (including audio, video, and images). They are designed for high-speed multimedia data with speeds ranging from 64 kbps (kilobits per second) to several megabits per second. The 3G systems will enhance the range and quality of services available for 2G systems by providing multimedia capacities and higher data transmission rates.

WCDMA is the leading global 3G standard selected by eight of the world's ten largest operators. It has been adopted as a standard by the ITU (International Telecommunications Union) under the name IMT-2000 (International Mobile Telecommunications - 2000).

It provides 50 times higher data rate than in present GSM networks (and 10 times higher data rate than in GSM networks with GPRS - General Packet Radio System). The first WCDMA systems available on the market handle more that 2 Mbps for local area access or 384 kbps for wide area access.

The specifications for WCDMA technology were defined by the 3rd Generation Partnership Project (3GPP)[2] by the end of 1999. The first full release of the specifications are called "Release 99", or just R99.

With later releases, WCDMA technology has evolved to a next level referred to as "HSDPA" (High Speed Downlink Packet Access), where the downlink peak data rates reach 14 Mbps and the systems data capacity is more than doubled with the same radio spectrum. It addresses both the end-users requirements for higher speed data transfers and improved service quality, and the operators' needs for more capacity and improved network efficiency.

Another step of the WCDMA evolution includes features to enhance the uplink with improved coverage, higher data rates and reduced uplink latency. This feature is referred to as "Enhanced Uplink".

WCDMA's radio network architecture is based on the general GSM architecture, which means that the GSM operators can integrate WCDMA to its existing GSM/GPRS networks, reducing the upgrade costs and ensuring a faster implementation of new services.

[2] The 3rd Generation Partnership Project is a collaboration agreement among a number of telecommunications standards bodies. The original scope of the 3GPP was to produce globally applicable technical specifications and technical reports for a 3rd Generation Mobile System based on evolved GSM core networks and on the radio access technologies that they support.

5.2.1 WCDMA Radio Access Network Architecture Overview

The main purpose of the WCDMA Radio Access Network (RAN) is to provide a connection between the handset and the core network, and to isolate all the radio issues from the core network. The advantage is to have one core network supporting multiple access technologies.

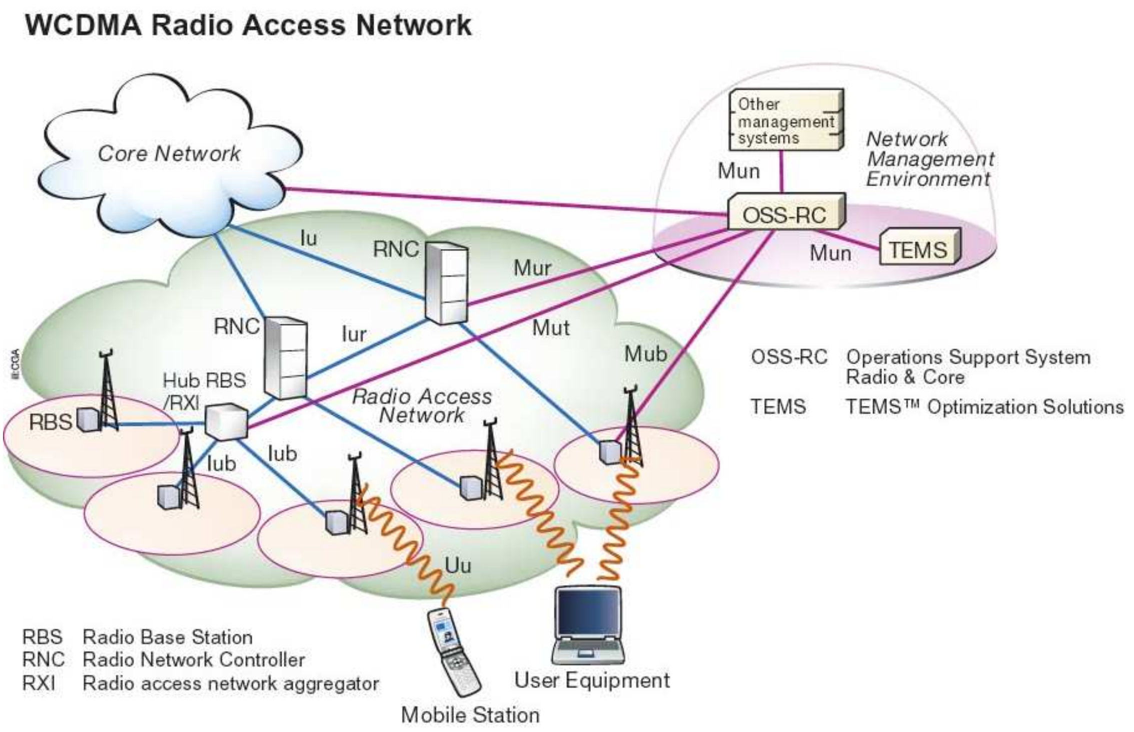

Figure 5.2. WCDMA Radio Access Network, *Source: Ericsson*

Figure 5.2 highlights the basic elements of Ericsson's WCDMA RAN architecture. The two most important nodes are:

- **Radio Base Stations (RBS or Node B)** - Provide the radio resources and handle the transmission and reception to/from the user equipment (handset) over the radio interface (Uu). They are controlled by the Radio Network Controller via the Iub interface.

- **Radio Network Controllers (RNC)** - They control all WCDMA Radio Access Network functions. The RNC manages the Radio Access Bearers for user data, the radio network resources and mobility. The core network and the WCDMA Radio Access Network are interconnected through the Iu interface.

The functions of the Network Management Environment include identifying the components of the network, ensuring the effective functioning of all network elements and providing security to the network. Operation and Maintenance functions are handled through the embedded management in the RNC and in the RBS, and Operations Support System for Radio and Core (OSS-RC) for GSM/WCDMA radio and core network management. The Operation and Maintenance Intranet uses the existing transport network and interconnects all network nodes, including OSS-RC.

5.3 Circuit And Packet Switching Technologies

Conventional cellular radio and land line telephony use circuit switching technology. Circuit-switched networks reserve a dedicated channel for the entire communication. A single user allocates an entire transmission resource continuously, even though no current transfer is active. Once the call is established through one route (going through specific switching centers), no matter how convoluted the route, that path or circuit will stay the same throughout the call.

In packet-based networks, however, the message gets broken into small data packets that seek out the most efficient route as circuits become available. Each packet may go on a different route, its header address tells it where to go and describes the sequence for reassembly at the destination. Unlike circuit switching, the calls don't take up an entire channel for an entire session. Bits get sent only when traffic goes on, when people actually speak or when data needs to be transfered. During pauses in a conversation a channel gets filled with pieces of other conversations. Thus, packet switching networks makes efficient use of scarce link bandwidth allowing high savings in network resources (Fernández 2003). Packet switching allows several telephone calls to occupy the amount of space occupied by only one in a circuit-switched network and this makes Voice over packet switched networks much cheaper.

Packet data networks allow the transmission of high speed data to and from devices that are always connected to the network. This is exactly the same fundamental enabling technology that was created when we went from dial-up internet access to high speed, always on (always-connected) internet access, now available at homes or businesses with cable modems, ADSL lines, etc. The latest mobile user equipments are always-connected to the Internet and the user only pays for the amount of data transferred or they may opt for wireless data packages that include bulk pricing on text messaging, emailing pictures and unlimited Internet access.

Third generation mobile systems support the conventional circuit based traffic, as well as the most speed demanding mobile applications that generates packed-data based traffic.

5.3.1 Network Traffic

Each mobile service or application generates either circuit or packet switched traffic. The services can be basically allocated in three categories: voice, video and data services. In Voice services we have the standard voice conversations with mobile phones. Video telephony is one type of Video service. In the Data services category we have file downloads (music, games, films), e-mail, web browsing and others.

Voice services use circuit switched resources of a mobile network. Voice signals are generated in real time, person-to-person calls. It can tolerate a certain degradation of quality (e.g. due to noise in the transmission channel) without becoming incomprehensible, but can not tolerate high blocking rates (i.e., when the connection of a call is refused) or large transmission delays.

Video traffic can be considered similar to voice (at least for our purposes), except at requiring more network capacity (e.g., the amount of information transfered in a video conference call is much higher that in a single voice call). Both are sensible to transmission delays. Thus, video services also generate circuit switched traffic.

On the other hand, data services (person-to-machine or machine-to-machine communications) generate packet switched traffic. They are often non real-time applications and the communication has usually a “bursty” nature and is asymmetric. That is, this type of traffic takes the form of intermittent bursts of information separated by intervals of silence at unequal rates in the two directions. Packet-data based services usually demand high data transfer speeds and more network capacity.

5.4 Initial Network Deployment Phase

In the initial network deployment phase the operators determine the amount of radio base stations that must be deployed, as well as all other infrastructure equipments that compose a mobile network, in order to provide service coverage either in a specific geographical region or to a specific fraction of the population.

The roll-out process is basically driven by the operator’s strategy for covering a certain fraction of the population or a certain surface area, but it must also satisfy the minimum coverage requirements specified by the country’s regulatory agency.

Different deployment strategies are usually considered by greenfield[3] and incumbent[4] operators to overtake the substantial investment in infrastructure that is involved during this phase.

The mobile market evolution gives the operators the opportunity to a large coexistence between 2G and 3G systems. Both systems may live together in the same town. Utilization of existing base station sites is important in speeding up WCDMA deployment and in sharing sites and transmission costs with the existing second generation systems.

For instance, an incumbent operator may deploy a WCDMA network in the downtown area to provide high rate data services and use its existing GSM base stations to provide mainly voice service in the remaining areas.

Operators migrating from 2G to 3G are able to achieve important savings in capital expenditures (CAPEX) by reusing part of the previous investment in infrastructure on their initial roll out phase. Co-siting GSM and WCDMA sites allow for major savings in site costs (e.g. license applications, location rent, site foundation, reusing antennas, feeders and transmission lines, etc). This leads to several considerable Return on Investment (ROI) benefits. Despite the coexistence advantage for incumbent operators, some extra radio base stations sites might still be required in order to cover the higher requirements on coverage, capacity and service quality imposed by 3G networks.

Another interesting strategy, specially for greenfield operators, is network infrastructure sharing, where the subscribers of multiple operators connect to the same radio access network via, e.g., roaming based methods. Depending on how much each operator pays, they should then be guaranteed a certain capacity in the shared network. It reduces

[3] Operators that have no previous (2G) wireless network deployed

[4] Operators that already have a 2G network deployed

substantially the high initial capital expenditure required for the network roll out. Another advantage of network sharing is that it lowers the operating costs in the long run.

Deploying a mobile network to provide service coverage is a continuous process that might take years to be completed. During this process, the amount of subscribers in the network may be very small and the volume of traffic flowing may be insignificant if compared to the available network capacity. In the next section we provide a description of some actions that can be taken to expand the capacity of WCDMA networks.

5.5 Expanding The Network's Capacity

Network capacity expansions are required when the volume of network traffic increase substantially or when the operator desires to provide increased service quality to its subscribers. There are several ways of expanding the capacity in WCDMA networks. One of them is simply to add new sites (deploying new Radio Base Stations). This is generally very expensive, since it includes tenancy agreements, permissions and site construction.

There are several expansion kits available on the market that provide the possibility to expand the coverage and capacity of the already deployed WCDMA networks by means of adding extra hardware and/or software on the radio base stations. Some options are to add new Cell Carriers, to add HSDPA/Enhanced Uplink carriers, to add extra Channel Elements and to increase the radio base stations' output power. Other capacity improvement strategies are available, such as parameter tuning (e.g. tilting antennas).

All these methods can be combined in order to achieve the desired capacity levels in the radio network. The next subsections provide some details of these options.

5.5.1 Radio Base Stations (Node B)

The Radio Base Station is responsible for the radio transmission and reception to and from the terminals over the radio interface. They are characterized by its coverage area, and can be basically divided in Macro, Micro and Pico base stations. The geographical area covered by a radio base station is called *site*.

A Macro Base station is found in all type areas (urban, suburban or rural). The Micro base stations can be found mainly in urban and suburban areas and can also be deployed to complement the Macro sites with extra coverage and capacity. The Pico base stations are usually deployed as in-building solutions, as well as to add extra capacity to areas where the traffic volume is very high, usually called *hot-spots*.

5.5.2 Cell Carriers

Radio Base Station sites are typically divided into sectors, typically three, but you might see just two and rarely six. Each of the sectors provide coverage in one specific direction from the radio base station. The radio signals are emitted by the cell carriers, thus more Cell Carriers can be installed in order to increase the capacity on a specific sector.

Figure 5.3 is an illustration of a 2 sector site with 3 carries. In fact, there are several different possible *Sectors* x *Carriers* configurations (e.g. 1x1, 3x1, 3x2, 3x3, 3x4, 6x1 and 6x2) depending of the Node B type.

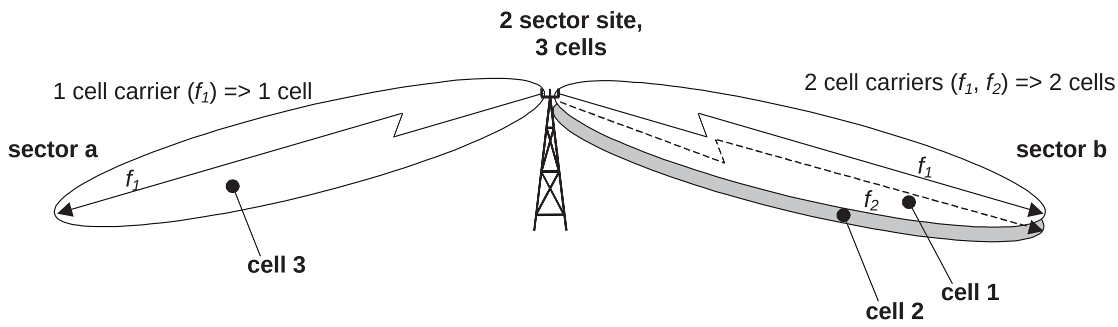

Figure 5.3. Illustration of site, sector and cell, *Source: Ericsson*

WCDMA uses radio channels that have a wider bandwidth than 2G digital cellular systems. WCDMA is normally deployed in a 5 MHz channel plan, compared to 200 KHz for GSM [Harte et al, 2004]. Thus, WCDMA provides much higher system capacity when compared with GSM.

Adding another carrier implies using another 5 MHz channel, which leads to the possibility of serving an extra volume of circuit and packet switched traffic. There are limitations on how many carriers may be installed per sector. It can be constrained by the type of the base station, but principally by the band size available to the operator. Typically, operator's have a 15 MHz spectrum, which allows them to add up to 3 carriers per sector in their networks.

Limitations on spectrum availability or base station capabilities may require the installation of new base stations in order to increase the network's capacity, a procedure called Cell Split. Adding cell carriers is often preferable to performing Cell Splits due to the large investments needed to add new sites.

R99 Cell Carriers can handle Circuit Switched (e.g. voice and video calls) traffic, as well as Packet Switched Traffic, packet-data based traffic (e.g. Web browsing, MMS, music downloads).

5.5.3 HSDPA

An enhancement to WCDMA known as High Speed Downlink Packet Access (HSDPA), boosts the air interface capacity and delivers a high increase in data speeds in the downlink direction. HSDPA also shortens round-trip time between network and terminals and reduces variance in downlink transmission delay. It enables operators to deliver advanced mobile broadband services such as Internet and corporate access. Its unprecedented data rates will allow users to download audio, video and large files or attachments significantly faster than previously possible.

It is not necessary to add another Cell Carrier just for HSDPA. A R99 Cell Carrier does not utilize the entire available transmission power and therefore, the unused power can be successfully utilized by HSDPA, as shown in Figure 5.4.

Figure 5.4. Power scheme for R99 and HSDPA, *Source: Ericsson*

Commercial HSDPA solutions enable HSDPA operation in any combination of Release 99 and HSDPA on separate or common carriers. Mobile operators have complete flexibility over how to deploy HSDPA in the way that best supports their business and operational strategy. For example, in areas where the traffic is usually high, an operator may choose to deploy one R99 carrier, as well as an extra radio frequency carrier to support only the HSDPA traffic (without having to share the transmission power with R99 carriers), whereas in areas were the traffic is not so high, like rural areas, they might choose to have a single Cell Carrier sharing transmission power between R99 and HSDPA traffic.

This is a particularly attractive option in areas where HSDPA coverage is required, but where the initial take-up in HSDPA handsets/subscribers is expected to be gradual. Additional HSDPA-dedicated Cell Carriers can be added later, based on traffic demand.

All WCDMA operators are expected to deploy HSDPA. The transition is smooth and cost effective, since it only requires adding some base band units in the radio base stations[5], as well as performing software upgrades. This will result in higher bit rates, higher capacity and better bit rate coverage.

5.5.4 Channel Elements (CE)

The radio base stations are equipped with a common pool of base band equipment responsible for processing signaling channels and the dedicated channels for user traffic. One Channel Element represents the base band capacity required to process the equivalent of one speech call.

The amount of CEs that is supported by one RBS can be different from one equipment to another, but the mainstream is 32 Channel Elements per RBS[6]. Each CE Kit supports a total of 16 Channel Elements.

[5]According to Ericsson's HSDPA deployment solution. However, the way HSDPA is deployed may vary among different suppliers.
[6]According to Tomas Sandin, KI/EAB/PV/N.

5.5.5 RBS Output Power

In order to provide the right downlink power for coverage and to provide a flexibility to match increased capacity demands overtime, the radio base stations can operate at different power classes: Standard Power (20W), High Power (30W and 40W) and Dual High Power (60W). The operators may also upgrade the RBSs to a higher power class to provide more power to the HSDPA channel.

There are several power kits available on the market that enable the operators to upgrade their radio base stations with increased output power.

5.5.6 Tuning Of Parameters

Another strategy for increasing the capacity in the radio network is by changing parameters values in the various elements of a radio network. The parameter tuning technique aims at short-term solutions.

The capacity increase is gained by decreasing coverage, service quality or a combination of both. Two different strategies are possible:

- **Always keep quality**: The service quality for each user is considered more important than the coverage. Thus, the capacity increase is achieved at the cost of coverage. For example, parameters may be changed in order to limit the coverage for high bit rate users. This would force the high bit rate users to use lower bit rates for packet-data transfers to a higher extent, providing room to a higher number of simultaneous users in the system.
- **Always provide coverage**: The coverage for each user is considered more important than the service quality. Thus, the capacity increase is achieved at the cost of quality. This could be accomplished by, for example, decreasing the power consumption per user. Allowing higher BLER[7] increases the number of simultaneous users at the expense of less throughput (lower bit rates) per user. The capacity gain is highly dependent on the amount of Packet Switched data traffic in the network. A higher BLER target results in a higher amount of retransmissions, which leads to a higher delay (worse service quality).

[7] BLER - Block Error Rate. A ratio of the number of erroneous blocks to the total number of blocks received on a digital circuit. BLER is used for WCDMA performance requirements tests.

6 Forecasting Model

This chapter briefly describes the model that is implemented in the forecasting tool. The overall reasoning behind the parts of the model as well as how they interconnect is described here. The chapter begins with an overview of the model followed by an initial discussion on expansions deployments dimensioning and descriptions of how the different aspects of confronting forecasted network demand with forecasted network capacity have been dealt with. The chapter ends by describing the assumptions that are made in this model. The detailed algorithm is presented in the Detailed Model Specification chapter.

6.1 WCDMA Forecasting Tool Model Overview

The WCDMA Forecasting Tool's integrated planning framework simulates the dynamic interactions within the WCDMA mobile networks sector under various plans and uncertainties (scenarios). The model's framework can be automatically calibrated, using generally available data, and modified to represent other particular infrastructure equipment, mobile operator or geographical area. It then becomes an explicative tool that dynamically simulates current and future conditions. It provides a laboratory in which planners can examine the long-range implications of programs and policies. As discussed before in Section 3.10, we have chosen a causal approach to modeling and much of the tool's pros described above are thanks to this choice.

Causal models are made up of variables that allow the user to directly relate changes in the real system to changes in the model. Causal models model cause and effect relationships. This is significantly different from models that look at variable correlation, with no implied causality. This causal model has a structure that mimics the real world, allowing the analyst to describe how the networks' capacity use changes. For example, infrastructure equipment sales in the WCDMA Forecasting Tool depend upon device and process efficiencies and market share, among other variables. Each of these variables has a real world counterpart and can be modified to reflect changes, either naturally occurring or through policy implementation.

The analyst can feel comfortable with the simulation results of a causal model because there is an understanding of why demand changes occurred. Changes in a causal model work through the model and the analyst can see exactly what effects these changes have. This transparency becomes particularly important when policies are being tested. Secondary and tertiary effects are picked up with a causal model that might be overlooked in other modeling endeavors.

Finally, using a causal model helps the analyst provide justifications for adjustments to the model or forecast. Instead of simply lowering the forecast because it is too high, the analyst can identify specific variables which may be highly uncertain - traffic forecasts, technology constraints, behavior variables - and adjust accordingly.

6.2 Initial Discussion On "How Big Will Be The Capacity Driven Expansion?"

As discussed before in Section 2.1, our model predicts needs for expansion in already deployed networks. Figure 6.1 depicts a simplified framework for our analysis.

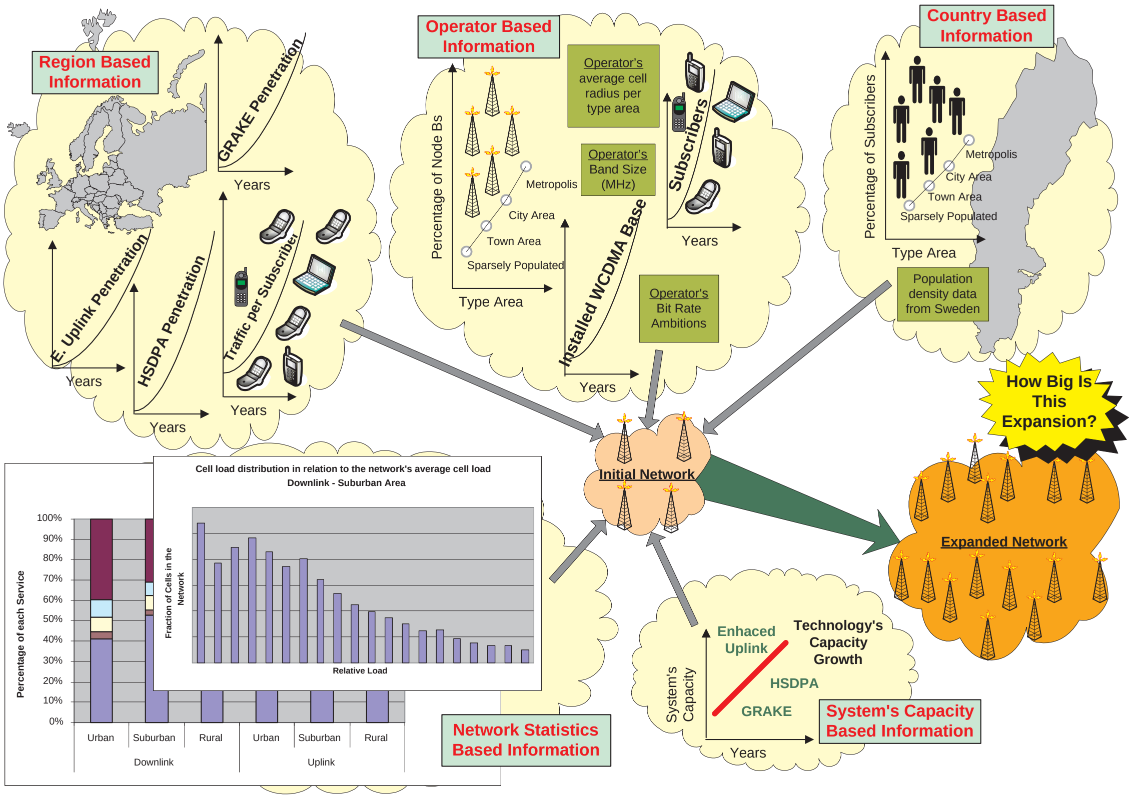

Figure 6.1. Analysis Framework - Inputs and Outputs

The smaller cloud in the middle of Figure 6.1 represents the present state of the network being analyzed. The bigger cloud to the right represents the network in the future, after expansions. How big will be these expansions is the subject of our studies. None of these states are static, year after year the network can grow for coverage as well as for capacity. Our model always considers the latest network layout in order to estimate how large will be the next year's capacity driven expansion.

The process of WCDMA radio network dimensioning is that through which possible configurations and the amount of network equipment needed for expansion are estimated, based on the operator's requirements related to the following (Holma and Toskala 2004).

Coverage:

- coverage regions;
- area type information;
- propagation conditions.

Capacity:

- spectrum available;
- subscriber growth forecast;
- traffic density information.

Quality of Service:

- area location probability (coverage probability);
- blocking probability;
- end-user throughput.

These requirements are some of our model's causal factors, their influence is modeled and their evolution path is accessed. Afterward, a scenario is simulated, the network is subject to constraints and tested using traffic forecasts, to determine whether capacity expansions are needed or not.

The radio networks' coverage dimensioning is estimated by the Coverage Model. Our model, through simplifications, performs worldwide radio networks' capacity dimensioning for five years ahead in time. Both models deal with quality of service concerns.

Returning to Figure 6.1, our model receives as input the actual network structure layout (and connected capacity) to, in an initial simplified explanation, confront it with user traffic (that will demand capacity from the network's resources). However, predicting expansions is not straightforward since the system's capacity also evolve in time and other influencing factors must also be considered in the analysis.

In the radio system planning process, coverage, capacity and service quality should be taken into account in order to achieve a cost-efficient radio network (Manninen 2001). All WCDMA deployed radio system is a balance between these three demands (Figure 6.2), and it is the operator's responsibility to maintain this equilibrium by performing expansions.

Given a deployed set of radio base stations, their capacity cannot be increased without suffering loss in either coverage or service quality (and vice versa). The only way to increase any of these dimensioning parameters without suffering loss on any of the others is expanding the network.

Furthermore, in case the network has to be expanded, how big this expansion will be is constrained by what is the need for extra capacity, which in turn is constrained by what is the radio base station (RBS) available capacity, which is a function of the RBS's coverage area. The expansion is also constrained by quality of service issues. In order to offer a better degree of service to its users, the operators might expand their network in a relation greater than that presented by the confrontation between traffic and capacity.

Therefore, in order to simulate the market dynamics, we have to simulate the networks' triangle dynamics. We had to model how different the RBSs' coverage area might be; consequently, how the RBSs' capacity may change even among RBSs in the same geographical area; and the impact of quality of service/strategy on expansions.

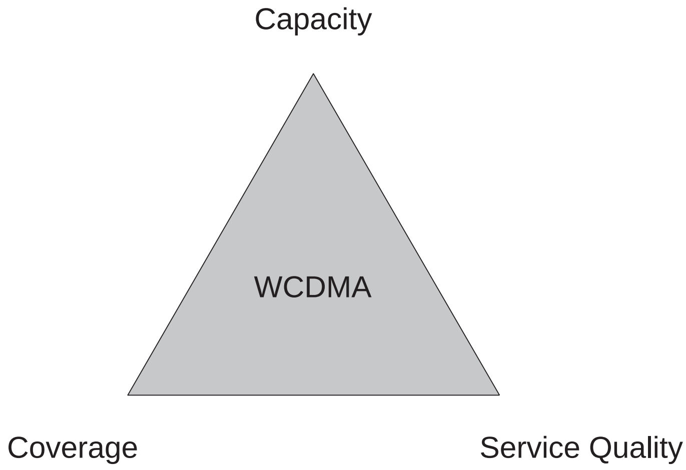

Figure 6.2. The three demands balance in a WCDMA system

A significant question about our work: How could we model capacity needs without having full information on coverage and service quality ambitions of the operators? It is important to underline that there is no available information on the worldwide radio base stations' coverage area and that it is not easy to gain information on the operators' degree of service/strategy. This is where the complexity of our modeling problem lay.

6.3 Initial Discussion On How The Parts Of The Model Have Been Interconnected

In Section 6.2 we have started the discussion about the trade-off between coverage and capacity that is inherent to any WCDMA system. Coverage is a constraint to capacity and vice versa. Capacity can be defined as the maximum carried traffic that is compliant with a given coverage constraint and coverage as the fraction of the offered traffic that can receive service with guaranteed minimum quality (G. Hampel 2003). See Figure 6.3.

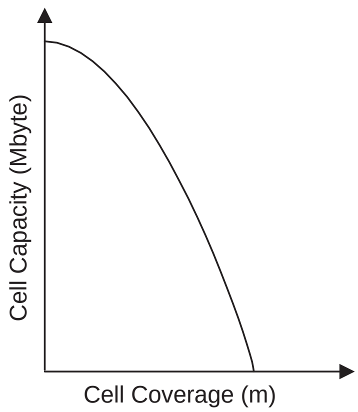

Figure 6.3. The tradeoff between coverage and capacity

The radio base stations in a network cover different areas. The area covered by each of these in square kilometers also varies through the geographical areas. Usually, the more urbanized the area, the more densified is the network, i.e., there are more RBSs/km^2 in the type area. In our model we have worked with four type areas:

- Metropolis Area
- City Area
- Town Area
- Sparsely Populated Area

More RBSs/km^2 mean that the coverage area of one RBS can be smaller without bringing coverage problems to the subscribers. The users will continue to access the services with the desired quality. The probability of coverage holes won't be increased. Figures 6.4 and 6.5 show two examples of network densification. In a metropolis area, the network is highly densified, the cells are small. On the other hand, in a sparsely populated area, the cells are quite big.

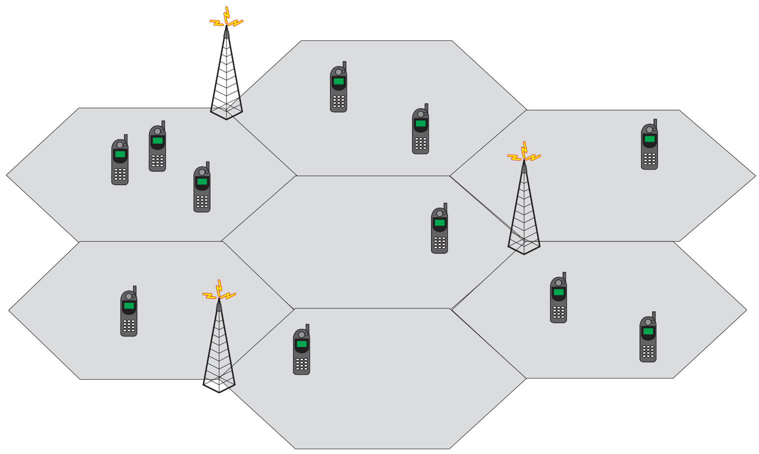

Figure 6.4. Densification example of a sparsely populated area

By densifying the network in a metropolis fashion (more RBSs/km^2, smaller cells), the intrinsic strategy is to gain from the capacity counterpart. Less coverage, more capacity. In this manner, the operator may serve more users, as it is expected to be in an metropolis/urban area. The more urbanized the area, the more users. Bringing back the WCDMA three demands balance, placing more RBSs in a region is a way to enhance capacity, service quality or indoor coverage.

The sectors of the base station do not cover the same area, and therefore, the sectors have to be treated individually with respect to a capacity expansion analysis. This is due to the fact that traffic cannot be moved between the sectors to handle stochastic peaks overloading one sector when others have spare capacity. Multiple carriers on an unique sector cover the same area. As discussed before in Section 5.5, a way to expand the network's capacity is to add new Cell Carriers to handle these peaks of traffic. Thus, our analysis is on the cell level. We analyze one cell, if this cell needs expansion we add a new cell to its sector.

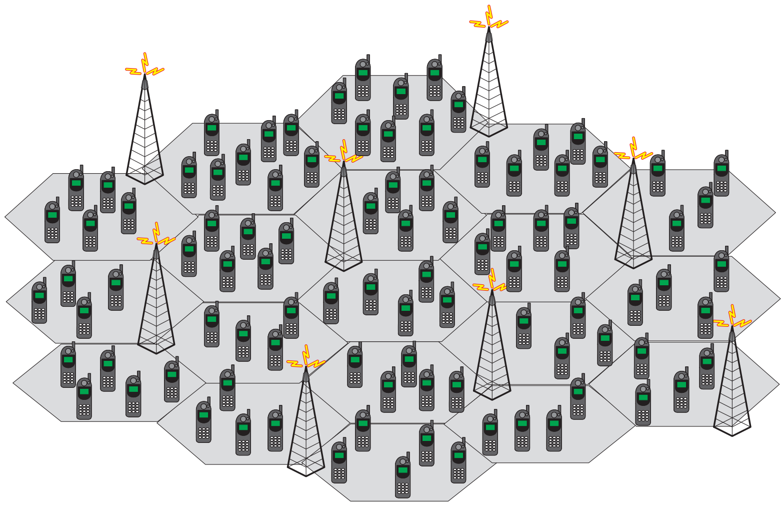

Figure 6.5. Densification example of a metropolis area

Now we have to build a methodology to determine whether a cell needs expansion or not. First, it is important to access the cell's capacity utilization. All in all, this is a matter of analyzing what the cell has to offer (capacity) and what is the demand on the cell (traffic and service quality constraints). Later, the capacity need has to be translated in type and amount of equipments needed for the expansion.

6.3.1 Uneven Distributions Throughout The Model

Distribution Of Radio Base Stations In The Type Areas

We have discussed about type areas and how different the network layout might be among distinct type areas. Thus, in order to simulate the networks' dynamics we had to model these layouts, we had to distribute the RBSs in the geographical areas. A measure of the percentage of radio base stations per type area has been used to unevenly distribute the RBSs.

We could make an estimate of the percentage of RBSs per type area by analyzing information on coverage requirements or ambitions, RBS density (parameter estimated on the Coverage Model) and size of the surface area to be covered (square kilometers).

Cell Capacity Distribution

If we assume that all radio base stations have a default layout, 3 sectors, each with one cell, also knowing the size in square kilometers of the type area being analyzed, and the number of RBSs in this type area, it is possible to calculate an approximate cell radius. The cell radius is the reaching limit of this cell's coverage area. A methodology for estimating the cell radius can be found in Appendix B.

Having information on the cell's coverage area we can use more accurate capacity estimates. From this analysis we could reach a distribution of cell capacities through the networks. It is not assumed in this work that all the radio base stations have the same capacity, but that their capacity is constrained by their cells' coverage area and sectors' tuning. Better tuned sectors will present better capacity in comparison to less tuned sectors, as discussed in Section 5.5.6.

Subscribers Distribution

Subscribers are also not evenly distributed across the type areas, their distribution follows the population distribution among the same type areas. People tend to live in urban conglomerates, and only small parts of the population live in rural areas. This distribution of subscribers will also influence the traffic distribution as our traffic forecasts are estimates per subscriber.

Traffic Distribution

Our model receives as input traffic forecasts per subscriber. However, as these are estimates for an average subscriber, when applied to the network (as a demand on the network's resources), every cell in the same type area would present similar utilization and expansion needs.

For our purpose there was a need of modeling how, inside a very same type area, cells may suffer different capacity utilizations. We had to elaborate on mobile devices usage patterns in different areas (services usage in different type areas in different networks) (Figure 6.6) and existence of user clusters in certain areas (also known as hot spots), making network load be unevenly distributed across a seemingly homogeneous region.

Our services usage pattern analysis is extremely valuable since this can access variations in traffic that are related to user behavior, a factor very complex in nature. These variations can be referenced to cultural patterns and may also be subject to change very swiftly, being sensitive to changes in pricing strategies and deployment of new services. Traffic data from real networks was used and studies on how to generalize these results to the remaining networks were pursued.

Regarding the network load analysis, we have worked with traffic data from field in order to build histograms on traffic distribution per cell with the objective to describe a typical network reality: not all the cells work fully loaded, some have problems with overload, and a few others have lots of spare capacity. From our distribution we were able to draw conclusions on the percentage of cells that receive much more traffic than an average cell and the percentage that receive less traffic than an average cell (Figure 6.7). Furthermore, we were able to say how more and how less loaded these non-average cells are. We will investigate this issue further in the next chapter.

6.4 Assumptions In Modeling

In this project, as for any forecasting system, several assumptions and simplifications had to be made in order to reduce the complexity of the model, and therefore making it possible for the users of the model to understand the logic and process behind it. We interpret that an accurate and reliable forecasting process should be comprehensive enough to identify the truly causal factors, but simple enough to explain to those who will need to make

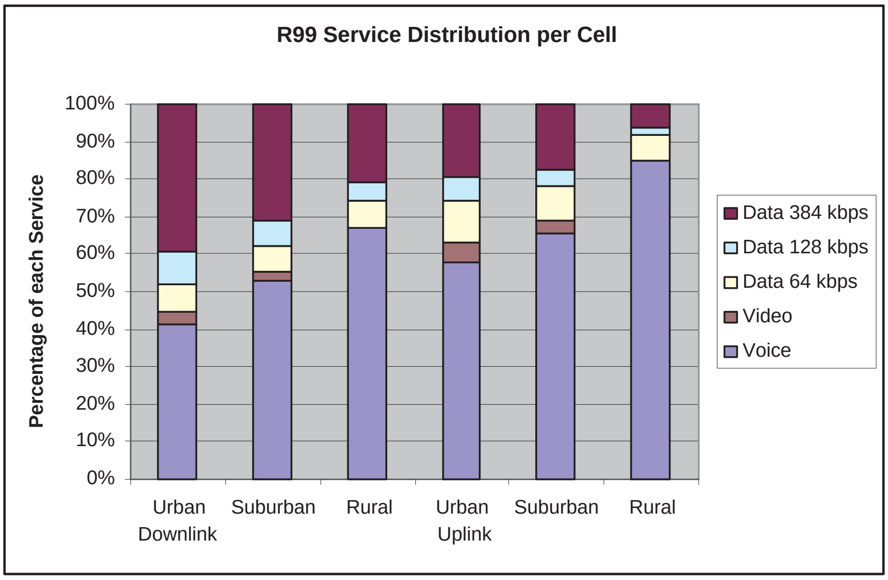

Figure 6.6. Illustration of mobile usage patterns in different type areas

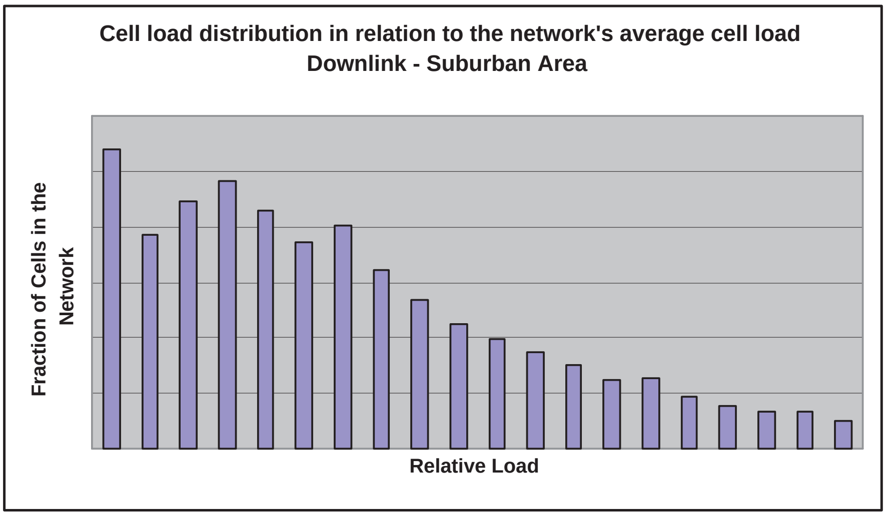

Figure 6.7. Suburban area example for cell load distribution in relation to the network's average cell load

decisions based on it.

Assumptions can also be made by the user when inputting his/her perceptions on figures like subscribers and traffic forecasts. It is important to stress that there is no right or wrong way of dealing with the inputs. Depending on what the user assumes to be the future state of a certain parameter, the model will perform reliable estimations according to his/her inputs. The model performs scenario-based forecasts, the user builds the scenario and the model provides the user with forecasts.

7 Detailed Model Specification

Here we set the bounds for the system. Both the tools and supplies that support the tool are better described here. The logic behind the model is presented by means of flowcharts of the algorithm. Here you will get detailed descriptions.

7.1 Main Parameters

The three main parameters in the Capacity Model are:

- network traffic;
- operator's bit rate ambitions;
- system capacity.

The general idea behind the Capacity Model is to check if the available network capacity is enough to handle both the volume of network traffic generated by the subscribers (voice, video and data traffic) and the quality of service that an operator intends to provide to its subscribers. Here, quality of service is measured in terms of packet data transfer speeds (bit rate), where higher bit rates means better quality of service.

Before getting into details of the model, we provide an overview of each of these parameters.

7.1.1 Network Traffic

WCDMA networks support both circuit and packet switched traffic. The traffic is referred to as *R99 traffic* and is handled by the Cell Carriers. When operators upgrade their core infrastructure to support HSDPA (High Speed Downlink Packet Access) and Enhanced Uplink, new types of high speed packet-data based services are offered for the end users. The data traffic generated by these new services is referred to as *HS traffic* (High Speed traffic) and is handled by the HSDPA-dedicated resources[1] of the Cell Carriers instead.

The Capacity Model receives downlink and uplink user traffic forecasts as input, representing the total volume of busy hour traffic generated by an average subscriber and accumulated during an entire month. This quantity is separated in R99 voice, R99 video and R99 packet data traffic volume, as well as in monthly traffic volume generated by an average subscriber through high speed packet-data based services, the so called HS traffic. Subscriber traffic forecasts must be input in the model both for the uplink and downlink.

WCDMA network capacity can also be divided in R99 and HS capacity and will be discussed in Section 7.1.3.

[1] HS traffic uses the power not utilized by R99 traffic, see Section 5.5.3.

In order to model traffic behavior in a network that can accommodate different classes of R99 traffic (such as voice, video and packet data), we need to identify a common traffic unit that encompass these three categories.

The system capacity for R99 traffic can be expressed in terms of the amount of simultaneous speech (voice) users in the system. Therefore, in our analysis any volume of R99 traffic is first properly scaled to an equivalent amount of voice users. For example, a voice call uses one “voice channel”, while a video call uses “several voice channels” in order to handle the extra capacity needs of the video stream. This is a simplification, but it makes capacity modeling significantly easier to handle.

On the other hand, when studying the system resources required to handle high speed packet-data based transfers, the the common traffic unit considered is the bit rate (data transfer speeds) in kilobits per second (kbps). Thus, the volume of HS traffic generated by the subscribers (through high speed packet-data based services) must also be expressed in terms of the bit rates.

More information on common traffic units will be provided in Section 7.1.3.

7.1.2 Operator’s Bit Rate Ambitions

In the initial years of operation, the volume of traffic flowing in WCDMA networks is very low. At least for today, since WCDMA is still in its maturity stage and the mobile market has not yet discovered all the potential provided by the technology. The volume of traffic in WCDMA networks will only be significant when (and if) the technology becomes widely diffused and used.

According to (Hall and Khan 2003), diffusion itself results from a series of individual decisions to begin using the new technology, decisions which are often the result of a comparison of the uncertain benefits of the new invention with the uncertain costs of adopting it.

The main benefit of 3G mobile systems like WCDMA is the ability to provide high speed data transfers to the end users, similar speeds achieved with fixed broadband connections. This may be one of the main drivers of the diffusion process of WCDMA technology, also supported by the actual period with rapid progress in the telecommunications industry, especially on the broadband Internet market segment.

Broadband Internet users are currently aware of the benefits provided by fast Internet connections. The main parameter analyzed when contracting a fixed Broadband Internet service is the average bit rate or the connection speed. It is believed that the same parameters will be carefully analyzed by new WCDMA subscribers looking for high speed Internet connections with mobility.

Faster Mobile Internet connections means better service quality. Different strategies will be taken by different WCDMA operators to provide better end user service quality. WCDMA operators must carefully dimension their networks to support the increasing user demand for high bit rates. The higher is the desired operator’s bit rate ambitions, the higher will be the demand for network resources.

The Capacity Model receives the operator's bit rate offering strategy, i.e., the bit rate (kbps) that a cell in the network must handle, both for the uplink and the downlink. The strategy does not need to be the same in all the type areas. This quantity will be compared with the model's input parameter, HS traffic volume, properly expressed in terms of kbps.

The greater between HS bit rate (estimated from HS traffic volume) and the operator's bit rate ambitions will be confronted with the actual HSDPA system capacity (in the downlink case) or Enhanced Uplink System Capacity (in the uplink case), in order to determine if extra infrastructure equipments are required.

7.1.3 System's Capacity

WCDMA system's capacity figures found in the Capacity Model are divided into R99 and HS system capacity. In both cases, the capacity is a function of the environment (Urban, Suburban and Rural), the coverage area of a cell (expressed in terms of the Cell Radius) and the average level of tuning of the cells in a network. They are also different for the uplink and the downlink (Holma and Toskala 2004).

The figures for R99 system capacity represent the amount of simultaneous voice users handled by a cell with a specific cell radius, for a given environment and level of tuning. Thus, the volume of R99 traffic (voice, video and packet data) generated by the subscribers should be properly represented in terms of voice users in order to be confronted with R99 capacity figures.

HS system capacity is divided in HSDPA system capacity in the downlink case and Enhanced Uplink system capacity in the uplink case. The capacity figures are expressed in terms of the maximum bit rate in kbps that can be handled by one Cell Carrier with a specified cell radius, for a given environment and a given level of tuning. It is also referred to as maximum cell or maximum system throughput.

7.2 Model Logic Overview

Figure 7.1 presents an overview of the logic behind the Capacity Model. The first two main parameters described in the previous section, network traffic and operator's bit rate ambitions, are depicted there (in italic font). System capacity is intrinsic to the Capacity Expansion Deployment Engine that will be presented in Section 7.2.2.

The model can be basically divided in three parts:

- Input parametrs,
- Non-Uniform Traffic Distribution Engine and
- Capacity Expansion Deployment Engine.

In general terms, the model works in the following way:

Input parameters are represented on the top of Figure 7.1 and comes either from the

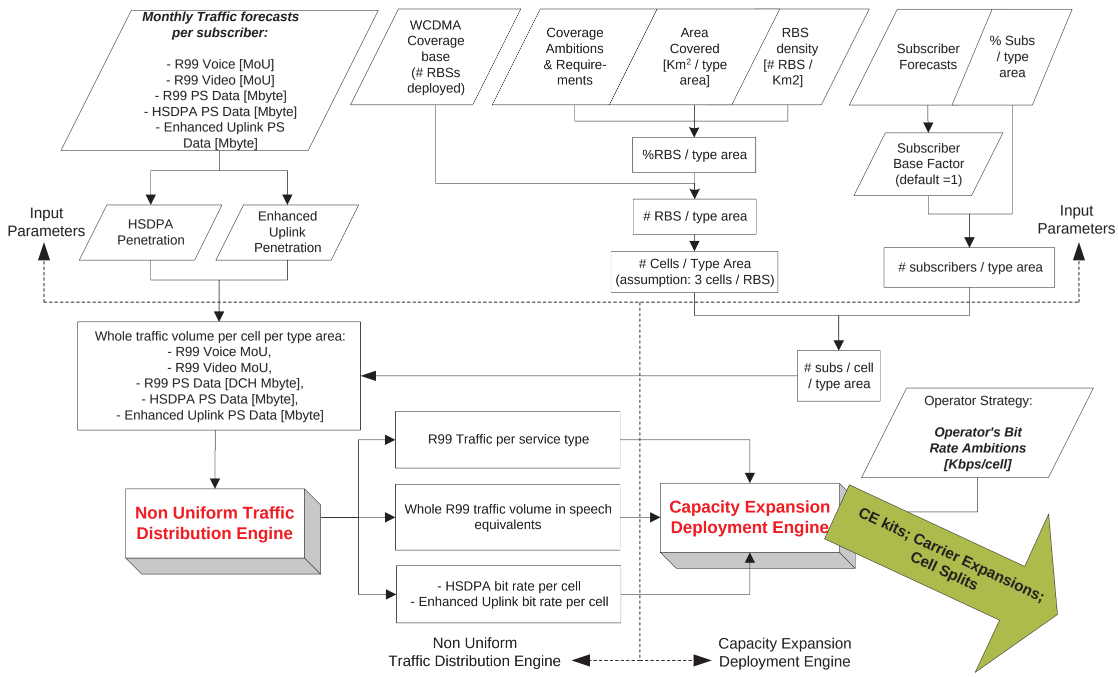

Figure 7.1. Flowchart - Capacity Model overview

Coverage Model (e.g. number of RBSs, RBS density and HSDPA/E. Uplink Penetration) or are manually inserted by the analyst (e.g. subscriber and traffic volume forecasts). Other input parameters are computed directly from the Coverage Model (e.g. total land area ($Km^2/type\ area$) and percentage of subscribers per type area).

These parameters are combined to provide an estimate of the volume of traffic per cell. This quantity is fed into the Non-Uniform Traffic Distribution Engine, which basically redistributes the traffic per cell in a non-uniform way, in an attempt to mimic the behavior of real networks. The engine uses data collected from field to derive the traffic distributions per cell.

Then, the distributed traffic and the Operator's bit rate ambitions are fed into the Capacity Expansion Deployment Engine, which finally estimates the amount of required network equipments.

Note that this analysis is performed separately for each type area and for each forecasting year. If in a given year of analysis the model determines that extra RBS's are needed in a certain type area, then these new RBS's will be added with amount of RBSs provided by the Coverage Model for the next year.

Note also that capacity expansion estimates are derived for the total WCDMA market. Thus, in order to estimate the market size for a specific company, in our case Ericsson, the total market figures must be multiplied by Ericsson's market share of the operator's CAPEX.

One drawback of this approach is that we are assuming that the system's capabilities will be the same for all vendors, which is in fact not true. For example, the power utilization scheme for HSDPA described in Section 5.5.3 may not hold for equipments from other vendors. This means that if HSDPA is to be deployed in certain areas where the traffic is usually low (e.g. rural areas), even though there will be plenty of spare cell capacity (since the amount of power required by R99 traffic will be very low), much more HSDPA carriers will be required.

7.2.1 Non-Uniform Traffic Distribution Engine

In real networks, the total traffic volume is not evenly distributed among all cells. Each cell has its own load pattern. However, there is not enough information about the distribution of traffic for all cells around the world, thus we have decided to treat this problem by categorizing each cell into an appropriate cell load category. This analysis is performed on the Non-Uniform Traffic Distribution Engine.

Figure 7.2 presents an schematics of the Non-Uniform Traffic Distribution Engine. The basic idea of this engine was introduced in Section 6.3.1. In general terms, the engine determines, for each cell load category, how much the volume of traffic is above or bellow the traffic volume for an average cell in the same environment (urban, suburban or rural), as well as which fraction of cells are manifesting this behavior in the real network. This process uses data collected from field for some WCDMA networks, if not for all.

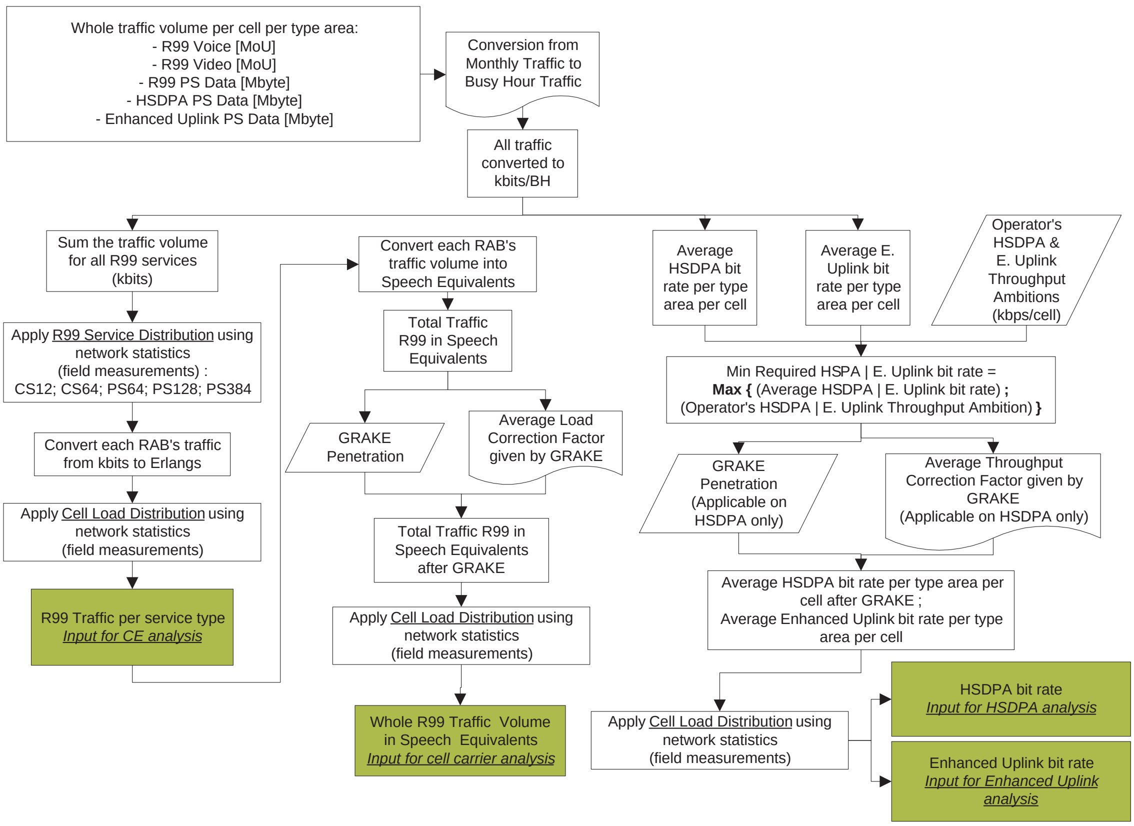

Figure 7.2. Non-uniform traffic distribution engine

There is also a GRAKE receiver gain factor considered in this analysis. The GRAKE is an improved type of receiver that can be deployed into the user equipments, resulting in a higher cell capacity, both in terms of R99 speech users and HSDPA througputs.

As an example of the Non-Uniform Traffic Distribution Engine, consider the busy hour packet data traffic volume for an average cell, located in an metropolis type area, as being 1000 Mbits per busy hour. By looking at payload data collected from field for this network, the engine could return that few cells are located in hot spot areas, and thus they would experiment higher traffic figures than an average during a busy hour. For instance, the output of this engine could tell us that 5% of the cells in this region present a traffic pattern above this average, with a traffic volume 10 times higher. This is a very typical pattern present in payload per cell statistics, since the number of hot spot sites is usually very low in real networks.

The engine returns the following estimates per cell, for each type area and for each cell load category (cells with different loads and the percentage of cell that actually lie in this category in the real network):

- **R99 Traffic per service type** - R99 traffic volume (separated by Voice, Video and Packet data), for each cell load category. This is the main parameter required for estimating Channel Element needs;
- **Whole R99 traffic volume in speech equivalents** - The total volume of R99 traffic during an average busy hour, expressed in terms of speech equivalents, for each cell load category. Parameter required for carrier needs analyses;
- **HSDPA & Enhanced Uplink Bit Rate** - The estimated throughput (bit rate, in kbps) for each cell load category. It the maximum between the operator's bit rate ambitions and the total volume of HS traffic during an average busy hour, properly expressed in terms of the bit rate in kilobits per second. This parameter is also required for carrier needs analyses.

These estimates are represented by the colored rectangles in Figure 7.2 and are fed into the Capacity Expansion Deployment Engine.

7.2.2 Capacity Expansion Deployment Engine

The Capacity Expansion Deployment Engine is divided in two modules:

- Cell Carriers & Cell Split Estimation module;
- Channel Element Kits Estimation module.

As the names suggest, the first module estimates the number of new sites and new Cell Carriers that must be deployed to support both the volume of user traffic (inputs of the engine) and the operator's bit rate offering ambitions.

The Channel Element Kits Estimation engine receives the volume of R99 traffic, separated by type of service (Voice, Video and Data), and determines the amount of Channel Element Kits that must be deployed to handle the traffic volume.

Cell Carriers & Cell Split Estimation Module

The main inputs of this module are the traffic volume and the operator's bit rate ambitions per type area, for each cell load category. In each cell load category, these quantities are confronted with cell capacity in the appropriate type area, and the model determines which cell load categories require expansions. Expansions are performed in all cells belonging to a given cell load category.

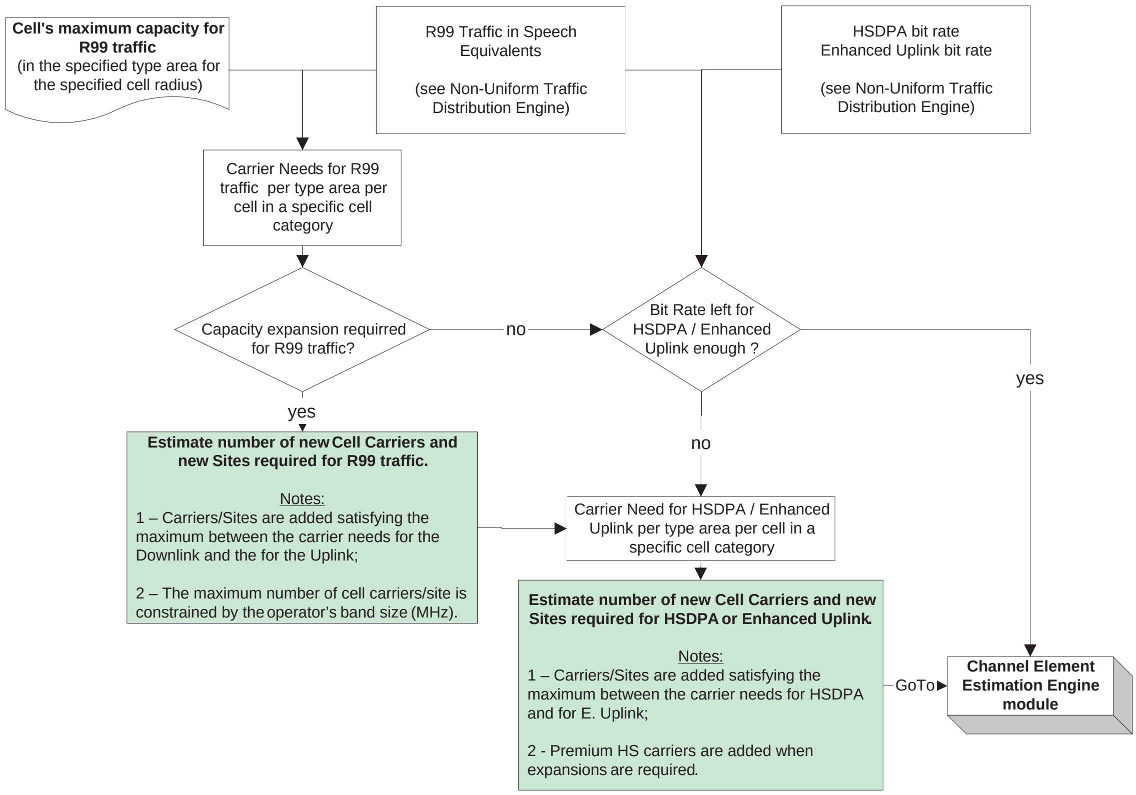

Figure 7.3. Capacity expansions deployment engine (Cell Carrier & Cell Split estimation module)

An schematics of the Cell Carriers & Cell Split Estimation module is shown Figure 7.3. The capacity of a cell is depicted in the upper left corner, and is divided in the maximum number of simultaneous R99 speech users, maximum HSDPA Cell Throughput and maximum Enhanced Uplink Cell Throughput.

Because of the trade-off between coverage and capacity (Section 6.2), the cell capacity will be higher in smaller coverage areas and vice versa. The coverage area of each cell is a function of the cell radius, hence an estimate of the cell radius must be accessed. The engine's methodology for estimating the cell radius can be found in Appendix B.

Cell capacity also depends on the network's tuning level. This module receives information about the actual level of tuning of the network. All capacity figures will rely on this variable. For example, a highly tuned network support more simultaneous users and higher bit rates per user than a low tuned network. The concept of capacity improvement by tuning of parameters was described in Section 5.5.

Describing the module's logic, first the total volume of R99 speech equivalents generated by user traffic is confronted with the R99 cell capacity. Then, estimates of the amount of new Cell Carriers and new Sites (new RBSs) that are required to handle the traffic are provided.

The maximum number of allowed Cell Carriers per sector is constrained by the operator's band size (or available frequency spectrum). For example, if an operator has license to operate at a 10 MHz spectrum bandwidth, then the maximum number of carriers per sector is 2, since in WCDMA each radio frequency carrier requires a 5 MHz bandwidth. Thus, in this situation and also considering a hexagonal network layout, i.e., each RBS providing service in 3 directions (3 sectors), the total maximum number of Cell Carriers that can be deployed per RBS is 6.

The next step is to check if extra sites or Cell Carriers are required to support the bit rate demands for high speed packet data. Now, expansions needs are determined by first looking if, after considering R99 traffic, the amount of power left for HSDPA (or Enhanced Uplink in the uplink case) is still enough to handle the bit rate requirements. If not, the model determines that new carriers dedicated only to HS traffic (HSDPA/Enhanced Uplink Cell Carriers) need to be deployed.

In Section 5.5.3 we introduced the concept of HSDPA. The concept for Enhanced Uplink is equivalent, however in the uplink direction.

A natural question that arises at this point is: How cell power utilization can be translated into maximum cell throughput (in kilobits per second)? In other words, given the volume of R99 traffic (R99 speech equivalents), what will be the maximum cell throughput supported by the cell?

- HSDPA Bit Rate estimation

  We could provide a solution to this problem with the assistance of a simulation tool (Olin *et al.* 2004) developed by Ericsson Research[2]. The proposed solution works in the following way.

  We have simulated the behavior of the system in different scenarios (several combinations of cell radii, type area and tuning level). The module receives R99 speech equivalent traffic and returns the maximum cell throughput, given in kilobits per second, for each scenario and traffic volume.

  Second degree polynomial equations of the form $y = Ax^2 + Bx + C$ were fitted to the output data and the coefficients A, B and C were estimated. Here, x is the volume of R99 traffic in speech equivalents (estimated by the Non-Uniform Traffic Distribution Engine) and y is the correspondent maximum cell throughput (in kbps) that must be estimated.

  An illustration of the curve fitting process is found in Figure 7.4. Coefficient C can be taken as the maximum system throughput per cell when no R99 traffic is present (no R99 traffic loading the cell).

  Coefficients A, B and C were implemented in the Capacity Model. Provided that the engine has determined the cell radius, type area and tuning level, a quick and easy estimation of the maximum cell throughput supported by the system for HS traffic is performed.

[2] This tool is not described in this document for confidentiality reasons. Ericsson's employees can find a detailed description in (Olin and Lundevall 2004).

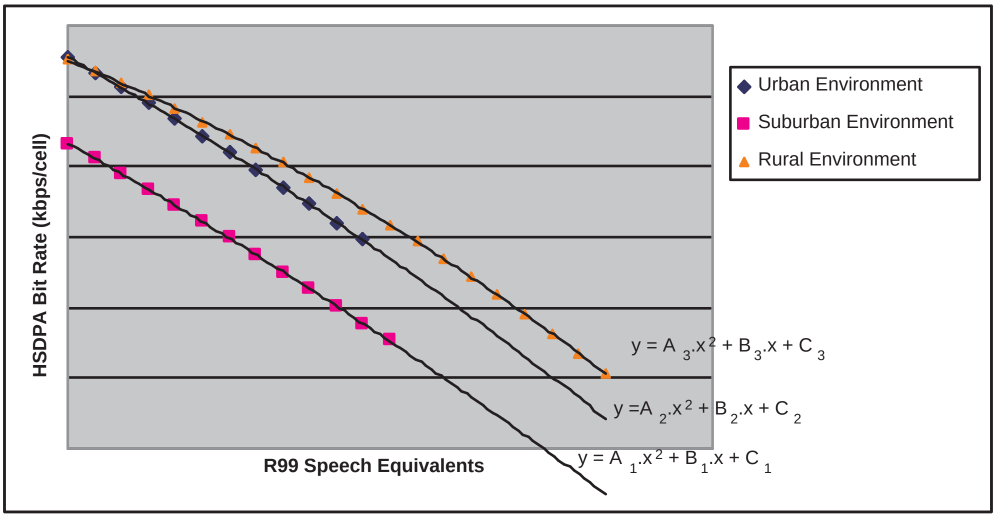

Figure 7.4. Curve fit: HSDPA cell throughput (450 meters cell radius, high tuning level)

The outputs of the system computed in this module (number of RBSs and number of Cell Carriers) are represented by the green rectangles in Figure 7.3.

Channel Element Kits Estimation Module

The last task of the Capacity Expansion Deployment Engine is to estimate the needs for Channel Elements (CEs) in the network. The concept of Channel Elements was introduced in Section 5.5.4. Figure 7.5 presents a flowchart of this module.

The Channel Element Kits Estimation module receives R99 traffic volume (separated by Voice, Video and Packet Switched Data) from the Non-Uniform Traffic Distribution Engine, and perform expansions analyses for each cell load category.

One Channel Element represents the base band capacity required to process the equivalent of one speech (voice) call. Video and Packet Data traffic demand more base band capacity than speech traffic. Baseband processing power is also different for uplink and downlink traffic.

The model computes the demand for CE resources in the network, checks what is the installed capacity, i.e., determine how many CE Kits are installed and what is the processing power of each CE Kit, and finally estimates the amount of new kits that must be deployed to handle the volume of R99 traffic.

The number of CE Kits estimated by this module is represented by the green rectangle in Figure 7.5.

Next chapter presents the forecasting tool software developed as an implementation of the Capacity Model.

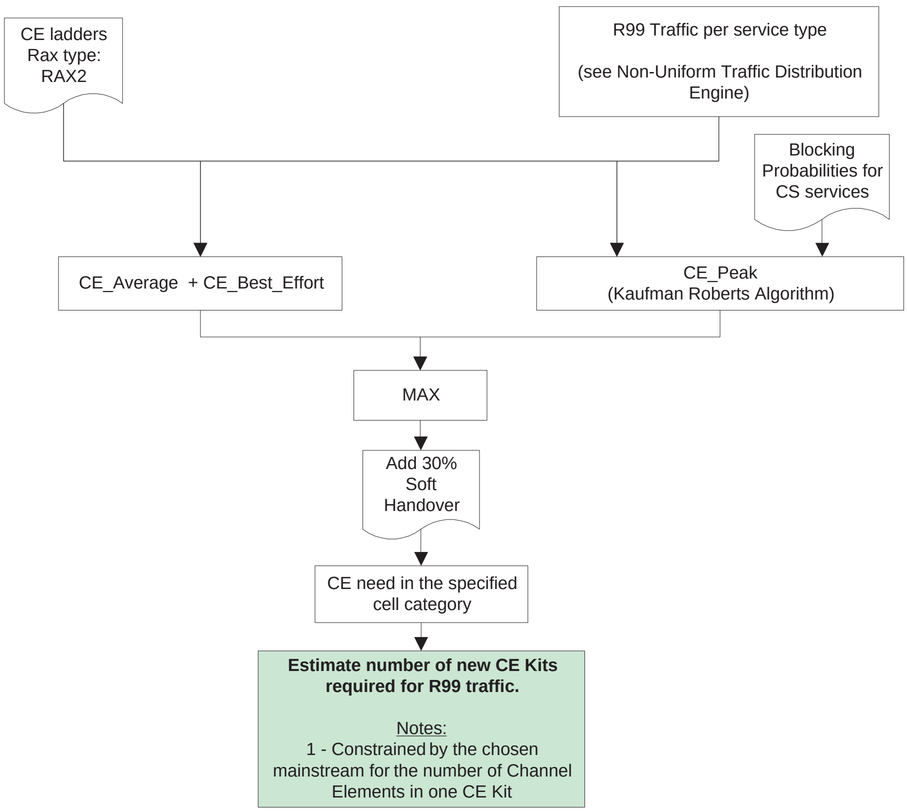

Figure 7.5. Capacity expansions deployment engine (Channel Element Kits estimation module)

8 Forecasting Tool

This chapter presents the WCDMA Forecasting Tool. Here you will get an insight of the tool's structure, design and layout.

8.1 WCDMA Forecasting Tool Structure

The forecasting tool is a Microsoft Excel based application and was programmed in Visual Basic for Applications (VBA). In this chapter we present some screenshots showing the tool's interface.

Some of the worksheets that constitute the core of the tool are[1]:

- Main Menu - This sheet is presented when the user opens the application. From here the user has access to all other sheets available in the tool. It also contains other features like the synchronization with the Coverage Tool and the ability to import a new Traffic Distribution Profile based on data collected from field. The User's Manual and the User Quick Guides are also accessible from this sheet. See Figure 8.1.

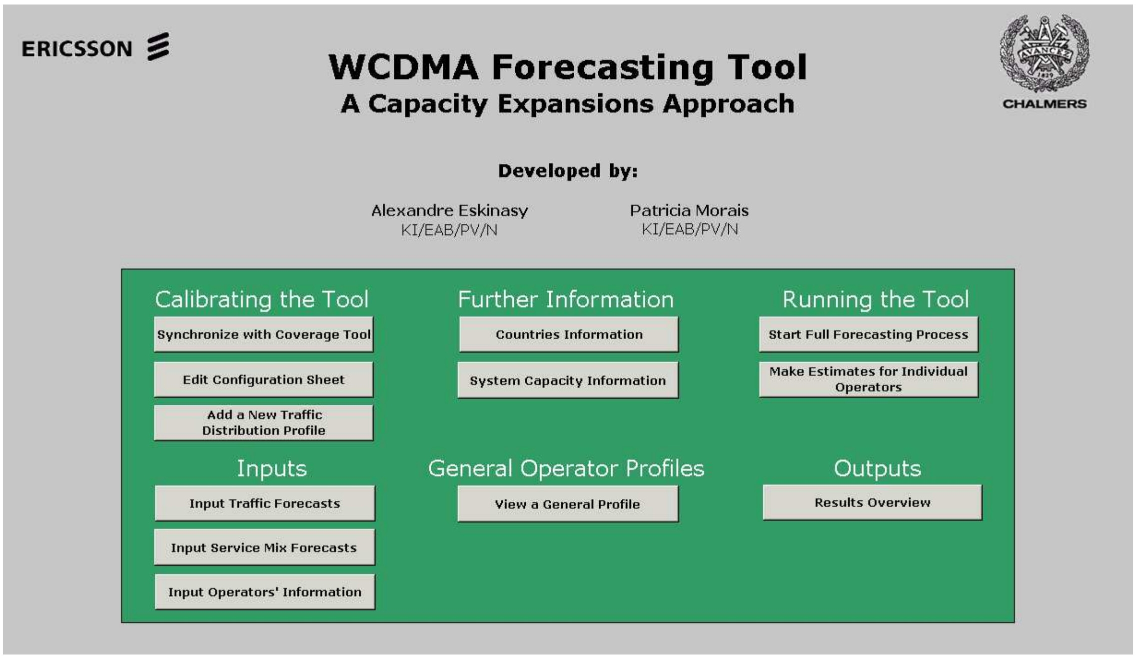

Figure 8.1. Main Menu

- Operators - The list of operators and its characteristics are defined here. Most of the information found in this sheet is imported or computed directly from the Coverage Tool with the synchronize function mentioned before. Other information must be

[1]For confidentiality reasons, the other worksheets are not presented in this document.

input by the user, for example WCDMA Subscriber Forecasts, Ericsson's Market Share of the Operator's CAPEX and the Operator's Bit Rate Ambitions. Clicking the CALCULATE button available in this sheet, the user activates the calculation engine. The outputs of this engine (estimates of infrastructure equipments required for capacity demands) are then presented in the Outputs sheet. The Operators sheet is shown in Figure 8.2[2].

Operators Sheet

Back To Main Menu
Go to Outputs Sheet
Go to Sanity Check Sheet

Header Row Colors:
Copied from the Coverage Tool
To be manually input
To be manually input or answered according to a General Profile
Computed from the Coverage Tool or answered according to a General Profile
Computed from the Coverage Tool

CALCULATE

					WCDMA Subscribers Forecast					
Operator name	Country	Region	Ericsson's Market Share	Band Size (MHz)	2 005	2 006	2 007	2 008	2 009	2 010
Operator A	Country 1	CEMA	25%	15	0	50 900	155 000	362 000	767 000	1 339 000
Operator B	Country 1	LAM	25%	15	0	0	0	317 900	1 179 000	2 494 000
Operator C	Country 2	APAC	100%	15	756 000	1 058 000	1 308 000	1 517 000	1 711 000	1 892 000
Operator D	Country 3	APAC	100%	15	81 600	382 000	953 000	2 133 000	3 925 000	5 681 000
Operator E	Country 4	WE	50%	10	137 000	355 000	827 000	1 602 000	2 435 000	3 006 000
Operator F	Country 5	APAC	25%	10	45 400	117 000	281 000	583 000	971 000	1 293 000
Operator G	Country 5	WE	100%	20	0	0	0	0	0	390 400
Operator H	Country 6	WE	25%	15	0	50 900	155 000	362 000	767 000	1 339 000

Figure 8.2. Operators sheet

- Countries - This sheet provides information about the coutries' distribution of subscribers among the different type areas. It is computed directly from the Coverage Tool during the synchronization process. See Figure 8.3.

Countries Sheet

Back To Main Menu

Legend:
Copied from the Coverage Tool
Computed from the Coverage Tool or answered according to a General Profile

		Percentage of Subscribers per Type Area				
Country name	Region	Metropolis	City Area	Town Area	Sparsely Populated	Not Allocated
Country 1	CEMA	22,6 %	14,5 %	10,8 %	43,9 %	8,2 %
Country 1	LAM	4,1 %	39,1 %	21,1 %	26,0 %	9,8 %
Country 2	APAC	11,6 %	19,9 %	16,3 %	52,0 %	0,1 %
Country 3	APAC	31,9 %	51,1 %	0,0 %	17,0 %	0,0 %
Country 4	WE	10,5 %	22,1 %	41,7 %	25,7 %	0,0 %
Country 5	APAC	16,5 %	15,8 %	10,9 %	52,7 %	4,1 %
Country 5	WE	6,3 %	34,6 %	22,8 %	30,7 %	5,6 %
Country 6	WE	2,0 %	12,3 %	52,0 %	33,5 %	0,3 %
Country 7	CEMA	0,0 %	27,8 %	14,0 %	57,9 %	0,2 %
Country 8	LAM	0,0 %	29,5 %	27,1 %	43,4 %	0,1 %
Country 9	CEMA	11,0 %	8,1 %	25,6 %	55,2 %	0,0 %
Country 10	CEMA	0,0 %	51,1 %	13,8 %	33,2 %	2,0 %
Country 11	NAM	0,0 %	10,9 %	26,7 %	56,2 %	6,2 %

Figure 8.3. Countries sheet

- Configuration - Here the user has the option to alter the default configurations, e.g., by changing the number of Cell Carriers per sector, the traffic peak hour factors or the factors to convert different types of traffic to speech equivalents. Other feature available in this sheet is a factor to increase/decrease the subscriber base, that can be used for sensitivity analysis. A list with the available General Operator Profiles available in the tool is also found here. See Figure 8.4.
- Outputs - This sheet presents the outputs of the model, which are the amount of CE Kits, Cell Carriers and RBSs required by capacity demands. They are divided into

[2] It is just an illustration of usage. The actual values were replaced by fictitious ones for confidentiality reasons.

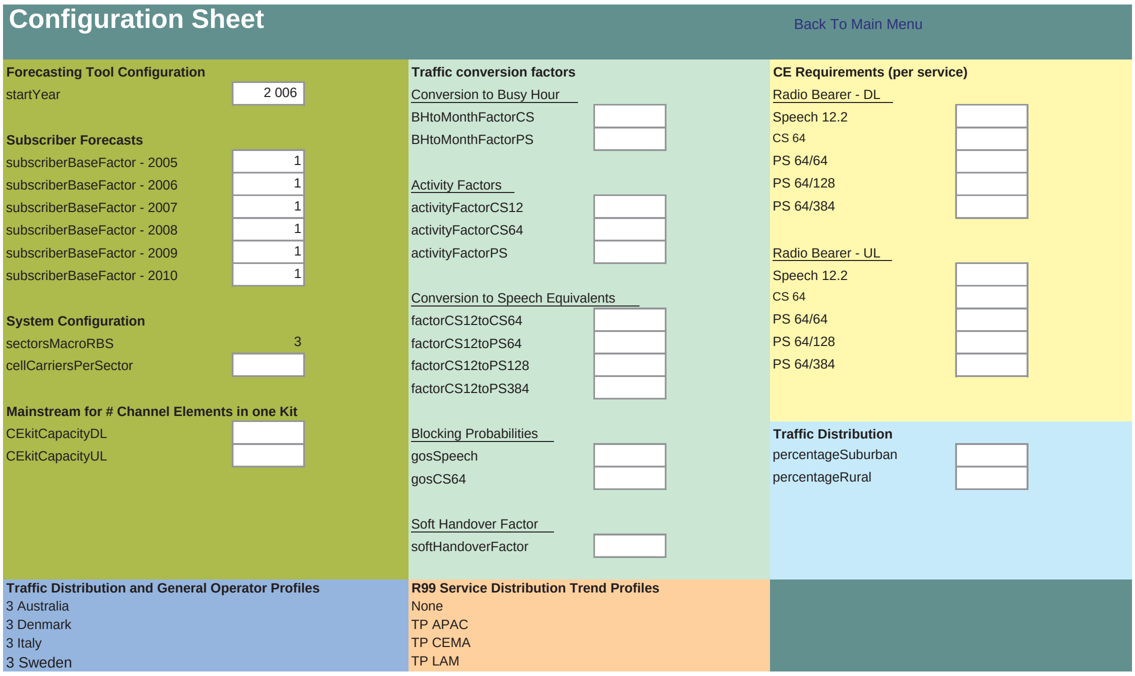

Figure 8.4. Configuration sheet

Worldwide and Ericsson's deliveries. It is also possible to check how much of the Cell Carrier expansions was driven by the volume of HSDPA or Enhanced Uplink user traffic or by the operator's bit rate ambitions. Figure 8.5 presents a screenshot of the Outputs sheet.

Outputs Sheet

Back To Main Menu

Go to Sanity Check Sheet

			Summarized Outputs														
			Worldwide Delivery Volume														
			Total #Channel Element Kits					Total # Cell Carriers					Total #RBSs (Coverage & Capacity)				
Operator name	Country	Region	2 006	2 007	2 008	2 009	2 010	2 006	2 007	2 008	2 009	2 010	2 006	2 007	2 008	2 009	2 010
Operator A	Country 1	CEMA	0	963	91	310	534	0	423	448	451	374	70	174	126	323	386
Operator B	Country 2	LAM	70	0	246	2228	4218	0	0	574	2842	2513	5000	500	500	393	1014
Operator C	Country 3	APAC	0	0	6128	116	308	0	0	0	44	148	0	0	1000	2018	4062
Operator D	Country 4	APAC	0	171581	9834	12109	28021	0	5419	12732	11335	12761	10000	18382	21263	25162	30407
Operator E	Country 5	WE	0	70	14204	6423	8959	28	35	7378	6026	6784	3500	2000	2048	1022	1441
Operator F	Country 6	APAC	0	543	212	921	582	0	47	8	127	155	10	50	82	115	153
Operator G	Country 7	WE	0	43268	1324	5765	17653	0	71	2205	4150	8156	0	7200	9139	8612	10136
Operator H	Country 8	WE	74976	0	46188	0	60549	0	0	0	0	0	12480	11526	8904	21492	19125
Operator I	Country 9	CEMA	0	36058	3058	0	9	0	0	0	0	0	0	6000	3000	2000	1000

Figure 8.5. Outputs sheet

- Sanity Check - This sheet can be analyzed in case there is an interest to verify the outputs in a more detailed stepwise. It provides a better picture of the calculations behind the model. One can also use this sheet to see where in the networks the capacity expansions are happening, i.e. in which of the type areas more expansions will be required. See Figure 8.6.

- DL System Capacity and UL System Capacity - These sheets contain information about the system's capacity for R99 and HSDPA (downlink case) and Enhanced Uplink (uplink case). The figures were estimated based on another software tool developed by Ericsson Research (Olin *et al.* 2004) and for confidentiality reasons we

Sanity Check Sheet Back To Main Menu

Operator: **Operator A (Country 1)**

Amount of Required Equipments:

Cell Load Category	Year 1															
	Metropolis				City Area				Town Area				Sparsely Populated			
	Cell Carriers	Cell Splits	CE (DL)	CE (UL)	Cell Carriers	Cell Splits	CE (DL)	CE (UL)	Cell Carriers	Cell Splits	CE (DL)	CE (UL)	Cell Carriers	Cell Splits	CE (DL)	CE (UL)
1	0	0	0	0	0	0	0	0	0	0	13	6	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	6	5	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0
4	0	0	0	320	0	0	0	0	0	0	5	4	0	0	0	0
5	0	0	0	0	0	0	0	0	4	0	4	3	0	0	0	0
6	0	0	0	0	0	0	0	0	3	0	3	6	0	0	0	0
7	0	0	0	0	0	0	0	0	3	0	6	4	0	0	0	0
8	0	0	0	36	0	0	0	35	2	0	4	4	0	0	0	0
9	0	0	0	24	0	0	0	0	2	0	4	4	0	0	0	0

Figure 8.6. Sanity Check sheet

will not show a screenshot of the DL and UL System Capacity sheets.

Also available in the tool are the sheets related to traffic distribution information collected directly from the operator's live networks. Again, these sheets will not be presented here for confidentiality reasons, since they contain sensitive information from several operators in the market.

9 Case Study: Greenfield Versus Incumbent Operators

We have analyzed differences in capacity expansions deployments between Greenfield and Incumbent operators with the help of our tool. The purpose of this analysis is to show that simple reasoning and assumptions can be translated to numbers by using the tool. We have tested a hypothesis and its validity is presented by means of two results.

9.1 Differences In Capacity Expansions Deployments

9.1.1 Node B Deployments

When analyzing differences in capacity expansions between Greenfield and Incumbent Operators, specialists might expect to have the following result:

Greenfield operators take longer to expand their network for capacity.

This is what we want to confirm and we have taken it as our hypothesis.

Let's elaborate better on our test case. We have worked with two different operators in two small countries in Western Europe. One of these operators is a Greenfield operator, the other is an Incumbent operator[1].

As Greenfield operators do not have an already deployed 2G network, they usually adopt a fast roll-out strategy in order to meet coverage requirements and be ready to launch the network. This means that at the very first years of the operator's life, huge investments are made in infrastructure and the operator covers a significant part of the population or surface area. A consequence of this roll-out strategy is that the operator will probably have lots of spare capacity in its network (at the first years of business), as the built capacity is not utilized well. There are no significant number of subscribers in the network, nor significant traffic per subscriber. Thus, capacity expansions in a Greenfield operator's network will be delayed if compared to when they happen in an Incumbent operator's network.

Incumbent operators are assumed to adopt a slower roll-out strategy. These operators have an already deployed 2G network and might co-site 3G with 2G, benefiting from the wide voice coverage that their 2G network is able to offer. Therefore, Incumbent operators are expected to start expanding their network for capacity much earlier than Greenfield operators. They do not have that much spare capacity and most probably have more subscribers (more load in the network).

In our base case scenario test we have used Ericsson's standard traffic and subscribers forecasts that are specific to each of these operators. Figure 9.1 shows the base case scenario. The graph presents the percentage of Node Bs that are deployed due to coverage

[1] We do not comment on their names for confidentiality reasons.

and due to capacity (cell splits).

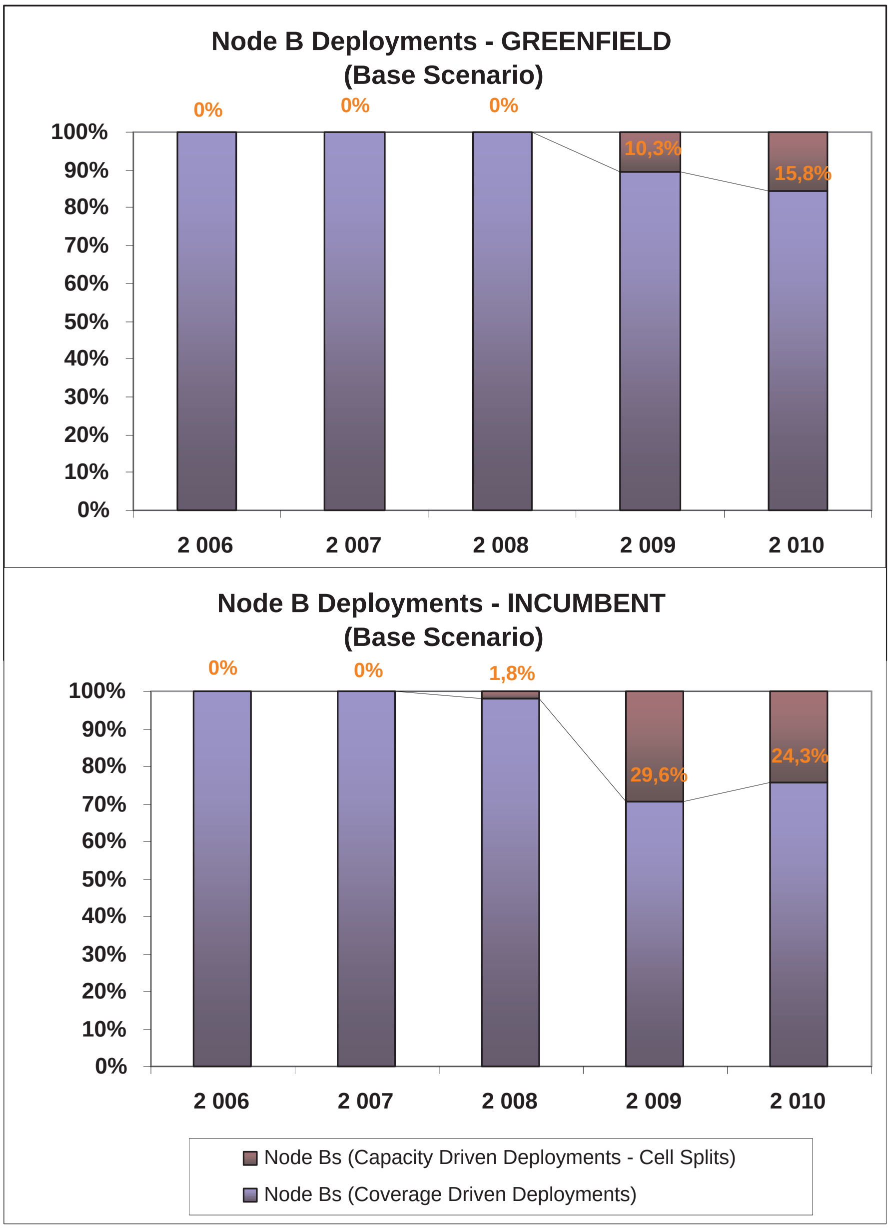

Figure 9.1. Node B deployments in a base case scenario - Percentage due to coverage and to capacity (cell splits)

In Figure 9.1 you can see that 1.8% of the total amount of Node Bs that the Incumbent operator's network requires in 2008 is due to capacity expansions. However, the Greenfield operator's network only starts to need capacity expansions in 2009, when 10.3% of the Node B deployments is due to capacity versus 29.6% in the Incumbent's network in the same year.

We have also analyzed the same operators in a scenario where they have half the expected number of subscribers in all years (half of Ericsson's standard subscribers forecast). Figure 9.2 shows the results for this low case scenario.

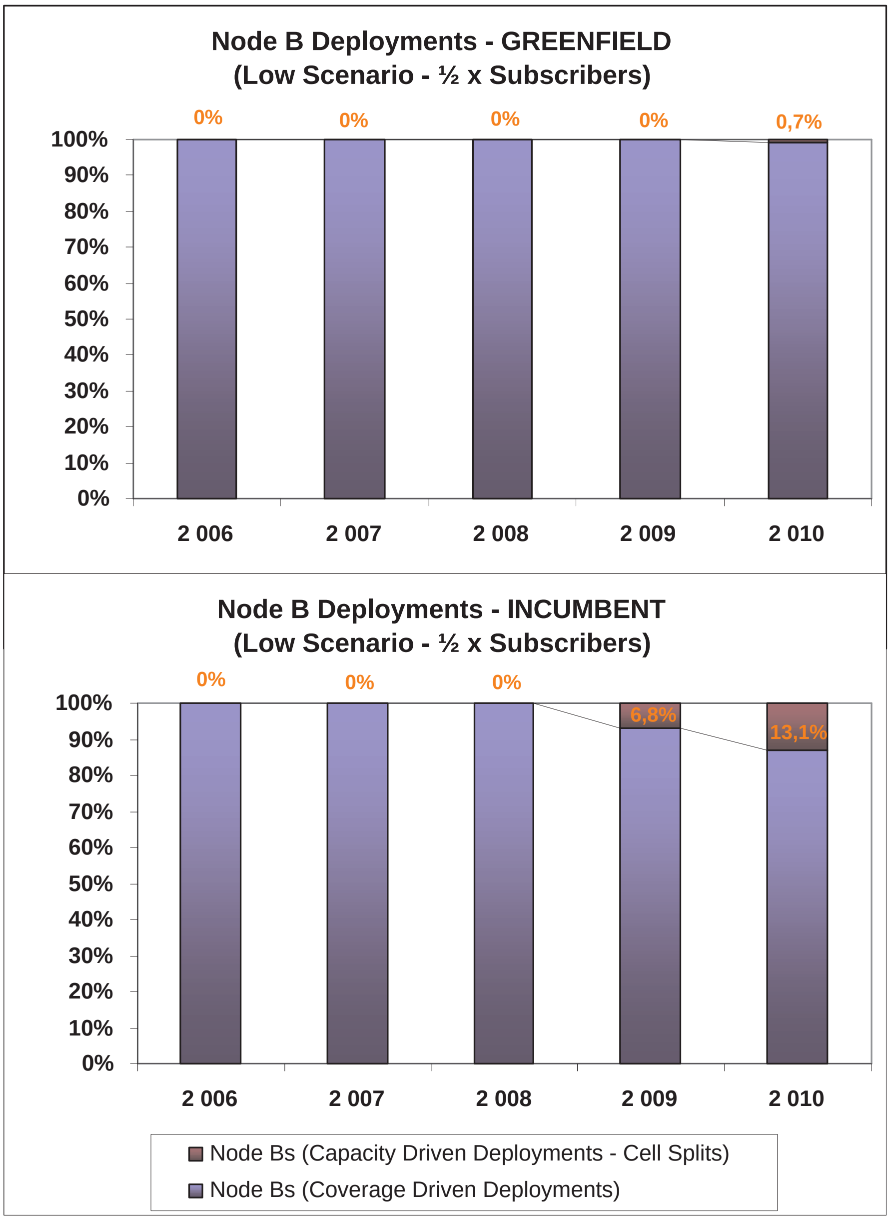

Figure 9.2. Node B deployments in a low case scenario - Percentage due to coverage and to capacity (cell splits)

The Greenfield operator case is specially sensitive to this low scenario. Its network's built capacity is practically not utilized and the consequence is that in a five years time frame, the operator only deploys capacity expansions in the last year, in a relation of 0.7% of the total amount of Node B deployments versus 13.1% in the Incumbent's case. See Figure 9.2.

This low case scenario, in a real world analysis, should be reviewed from a financial standpoint. This Greenfield operator, with high infrastructure spendings in the first years of business and low revenue from subscribers, might present a clearly negative financial state and, as a consequence, do not require any capacity expansions in 2010.

9.1.2 Channel Elements And Cell Carriers Deployments

In the last section we have analyzed a low case and a base case subscriber scenario and their influences on Node B deployments. Here we present analyses on Channel Elements and Cell Carriers deployments in a high case scenario. We compare infrastructure deployments in a case where we have used twice Ericsson's standard traffic forecasts to the same deployments in the base case scenario, in order to answer the question: How many times more deployments are required than in the base case?

We continue analyzing the same operators in the same countries and thus we can again draw conclusions on the differences between their capacity expansions deployments.

In Figure 9.3 we see that if the Incumbent operator experiences twice the expected traffic, it would require 17.2 times more Channel Element Kits than it would require in the base case scenario in 2006. The Greenfield operator would require much less, only 1.3 times more. This again confirms the assumption of spare capacity and delayed expansions in the Greenfield's network. Even twice the expected traffic does not push the capacity expansion requirements to higher levels (if compared to the expansion levels in the Incumbent operator's network).

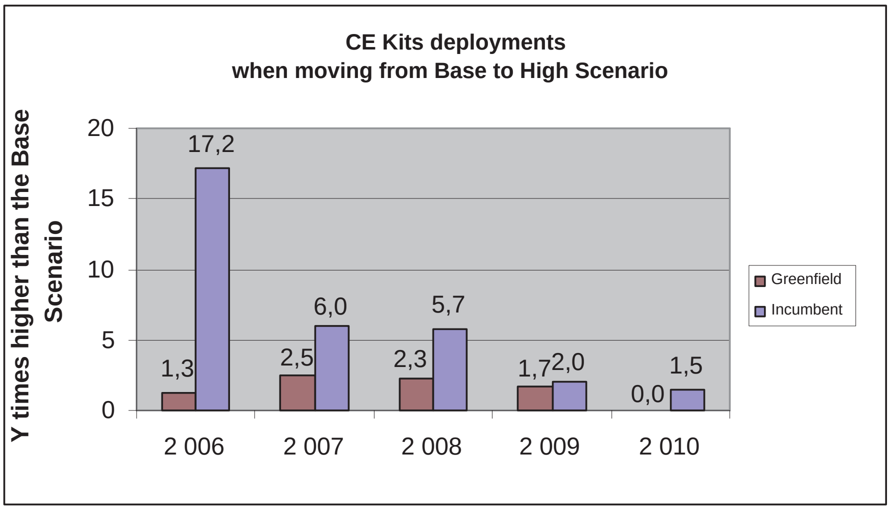

Figure 9.3. Channel Element Kits deployments in a high traffic scenario in relation to the deployments in a base case scenario

A similar behavior can be noticed in the Cell Carriers deployment analysis. The Incumbent operator requires 41 times more Cell Carriers than in the base case in 2006, when the Greenfield operator requires only 2 times the number of Cell Carriers required in the base case. See Figure 9.4.

As you can see from the graphs, there are huge differences in capacity expansions requirements between two different operators. The differences can be due to a number of factors, for example, the way the network was built, its layout, the number of subscribers, etc. The analyses and conclusions are not limited to the ones presented here.

The Capacity Tool has been designed in such a way that it is easy to draw detailed parallels, enabling its users to achieve interesting conclusions simply by comparing operators or by

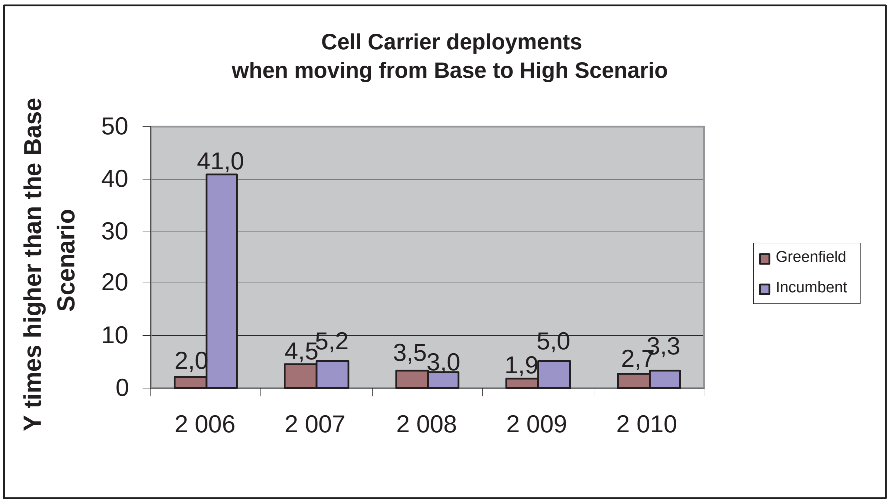

Figure 9.4. Cell Carriers deployments in a high traffic scenario in relation to the deployments in a base case scenario

performing a detailed analysis in a specific operator.

10 Analysis And Discussion

The model developed in this project is discussed here in terms of its reliability, validity and relevance. The strengths and weaknesses of the tool are also analyzed and discussed.

10.1 Reliability Of The Model

Our model has not been tested since we do not have data on capacity expansions from real networks to compare our results with. The operators have not yet started to face expansion needs due to increase in traffic levels. Therefore, it is difficult to make judgments regarding the model's reliability as no formal tests of model robustness have been performed.

It can be found on (Armstrong and Grohman 1972) a discussion on how causal models seem to offer more accurate long-range forecasts and also case analysis results showing that the accuracy of causal models relative to other methods increases as the time horizon of the forecast increases. Further inferences on causal models accuracy can then be performed when the user of this model starts to receive realized values for the subject of the forecast.

Furthermore, one forecast element is missing in our results: probability. Every forecast must incorporate some indication of the uncertainty which is associated to it. This can be evaluated from an analysis of the accuracy of previous forecasts for the same or similar phenomena. But again, as we don't have accuracy results we did not perform any uncertainty analysis.

The purpose of a sales forecast is to aid the decision maker. Even though attention will inevitably be focused on the median of the forecast in taking a decision, the uncertainty incorporated in the forecast enables an assessment to be made of the risk associated with the decision. All in all, there is no assessment of uncertainty, risk or error in this work.

10.2 Validity Of The Model

We have received positive feedbacks on our model from Ericsson's employees and they have stressed that the tool will also be an important source of knowledge to other colleagues. Being a simulation instrument, the tool allows for system and environments' analyses and comprehension. This is mainly a consequence of our modeling approach. Causal models are considered a tool conductive to support thinking, group discussion and learning in management teams (Morecroft 1992).

The model was made as universally applicable as possible. This means that the model was developed with the concern that the decisions and assumptions made through the designing process should apply to operators on a global level. Also, the process of designing traffic distribution figures (Section 6.3.1), has been automatized in the tool. In case there is more data from field from other operators, the tool will receive a simple data file and will make all the necessary calculations to build the histograms on cell load distribution and services usage pattern. This feature is of extreme benefit to the model's validity, since today some continents have few or no WCDMA systems, and it is difficult to make traffic distributions assumptions on such continents.

One important strength of our model is the way it gathers information from different sources and builds a scenario over which a forecast can be performed. The model receives information from the Coverage Model (from what cell radii can be calculated and which has a database of population density from more than 50 countries), data traffic information from field (from what load histograms are drawn) and Ericsson's experts knowledge about assumptions to be made on the inputs.

Different investment banks and research groups make forecasts on the 3G mobile market. These companies have developed their own models to forecast the WCDMA market size. It is not our mission to judge their model's validity. However, we would like to stress that these companies do not have access to the same information as we have through Ericsson's internal sources. The strength mentioned above relates to this and is one of our model's most important differentials.

10.3 Model's Relevance

The formal specification of this project has a discussion on the relevance of the causal factors. It also lists the factors that were considered in the model and those that were taken out of the scope. One factor that was deemed to be an important driver to capacity expansions was equipment pricing. However, due to the lack of data and explicit relations between sales and pricing strategies, this was not considered in the model. Our model is artificially small to keep the problem manageable and the objectives in sight.

Our model assumes that capacity expansion needs may be directly translated to equipment sales. However, this translation might only be valid in case the analyzed supplier offers a competitive pricing strategy. On the other hand, accurate market share estimates may also help validating equipment sales estimates. Therefore, even though extra strategy and pricing related factors could be included in the model, the market share factor is capable of increasing the validness of sales estimates.

10.4 Strengths And Weaknesses Of The Model

10.4.1 Strengths

- The model has the capacity to reevaluate reality from a new perspective. For example, in case it is foreseen an exponential increase in traffic or a new technology release may double the system's capacity, the model can reestimate equipment sales.
- Allows integration of qualitative and quantitative variables in consistent structure.
- Is based on premise that future is not necessarily based on past.
- Is based on a very applied system modeling approach, thus very functional.
- Is able to simulate different scenarios, thus providing high flexibility.

- Uses information collected from real networks in order to distribute the network traffic, instead of assuming an uniform distribution.
- Implemented over an intuitive an easy to learn interface based on Microsoft Excel, which is widely diffused among the corporations.

10.4.2 Weaknesses

- No validation process for estimates and no assessment of uncertainties.
- No tests for sensitivity or marginal effects.
- No formal tests of model robustness.
- Limited forecasting horizon (5 years ahead).
- The users of the Forecasting Tool are obliged to understand how the system functions instead of simply analyze results.
- Large number of parameters to set.

11 Conclusions

This chapter summarizes the discussions in the Analysis and Discussion chapter. Here we access the validity of our results and comment on their significance. Our main findings and conclusions are also presented here.

11.1 On The Modeling Approach

Given the lack of historical sales in highly dynamic, innovative telecommunication markets, simulation based approaches offer a valid option to capture the complexity and inherent feedback structures of such environments and to support telecom managers in their strategic decisions. In a simulation, all assumptions are required to be stated explicitly. They are translated into a set of equations to show the interdependence of the various assumptions and the resulting consequences. However, simulations can only show the consequences of the assumptions entered by the users of the model, regardless if these assumptions are correct or false (Forrester 1970).

Simulation based models have two main origins. The first is the crisis of forecasting techniques (in technology forecasting) that rely on the assumption that looking at the past and using straightforward mathematical extrapolations is the best way to predict the future. Although an indispensable management tool, it is useful for short-term analysis only. Predictions of the effects of changes in the environment are difficult, and forecasts of future trends are frequently value free. The second origin is today's business environment, characterized by dynamic complexity, discontinuity, turbulence, and high speed of change.

Our approach to modeling provides users with the ability to perceive reality in this context. This is built around a central theme that focuses attention on causal processes and decision points; provokes consideration of how small variations in a few relationships can have profound consequences; supports the necessity of integrating qualitative and quantitative information into a consistent picture; and is not a simple forecast, but is built on the premise that the future is not the product of the past (Georgantzas and Acar 1995).

11.2 On The Model's Evaluation

The orderer of the Forecasting Tool and other Ericsson's employees involved in our assignment were particularly satisfied with the approach followed by us in order to make traffic load distribution based on updated data from real networks (Section 6.3.1) and our new way of analyzing high speed traffic driven expansions from curve fitting of R99 load versus bit rate left for high speed packet data traffic (Section 7.2.2). However, we cannot state at this point whether the tool will be successful in helping Ericsson create its long-range forecasts and support the decision makers.

The following subsections summarize the discussions on the Analysis and Discussions chapter, focusing on the reliability, validity and relevance of the model implemented in the tool.

11.2.1 Reliability

Our model has not been tested and therefore no accessments on the model's results accuracy have been performed. Furthermore, no uncertainty analysis has been made. There are no estimates for uncertainty, risk or error in this work.

11.2.2 Validity

Being simulation based, the tool, apart from being a support instrument for decision, may also be an important source of knowledge to Ericsson's employees. Regarding the applicability of the tool, it was considered during all the designing process, that the tool should be able to work with operators on a global level. Even though at this point there is no/few data from operators in some countries, the tool is ready to receive new data and model their networks in a next-to-reality way.

11.2.3 Relevance

Our model is artificially small to keep the problem manageable and the objectives in sight. However, we have focused on studying all the parameters that significantly influence the result.

11.3 On The Main Findings

We believe that we have gained a good understanding of the main forces driving our problem. WCDMA is an extremely complex technology and we were able to model its dynamics in a simplified way by talking to specialists, looking forward to feedbacks on our results and studying the object of our forecast to the highest extent and of course, striving for simplifications. This is where the value of our effort lay, in the ability of building a simplified model of a highly constrained problem.

12 Further Research

This chapter describes the areas of relevant further research as well as the possibilities for improvements we have found along the project path.

12.1 Suggested Further Studies

Further studies should be carried out about the capabilities of other vendors' equipments. As discussed in Section 7.2, the tool makes worldwide estimations, i.e, the model's outputs are for the entire WCDMA market. This means that capacity expansions estimates are made even for operators that are not under Ericsson's portfolio, and consequently do not run networks with the same features/capabilities as Ericsson's networks, but assuming Ericsson's products specifications. Thus, the question to be answered is: Are there significant differences (in terms of system's capabilities) that should be considered when making estimations for other vendor's networks?

12.2 Suggested Model Improvements

The following bullets present some areas for future improvements in the model.

- Future product evolution and how evolution will affect the need for capacity expansions must be accessed. Gains with the implementation of HSDPA and Enhanced Uplink are already implemented in our model. However, the WCDMA performance roadmap is very promising in terms of evolution in the near future and this must incite further questioning on the impacts each evolution step may bring to the way traffic loads the networks.
- All our work was directed to answer questions about Radio Base Stations' capacity expansions but there are still lots of questions to answer from the Radio Network Controllers point of view as well as from the lub transmission counterpart. Future studies should focus on analyzing impacts of traffic growth onto other radio access network's (RAN's) elements.
- As high-speed traffic grows, a new study on networks' traffic distributions must be performed. It is needed to examine how different apart R99 traffic distribution figures might be from HSDPA traffic distribution figures. In our model HSDPA traffic is distributed according to R99 traffic distributions from field, a necessary assumption as there is no significant HSDPA traffic loading the networks at this point.

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Appendix A

Cell Radius Estimation

The default assumption in the Capacity Model is that each radio base station provides coverage in three directions (3 sectors). Some further assumptions:

- The geographical area covered by cellular radio antennas is assumed to have an hexagonal layout, like in Figure 6.4.
- The cells placement is assumed to be homogeneous inside each type area. This is a simplification, since in real networks the radio base stations are not strictly uniformly distributed among the geographical area. However, information about coverage area for every radio base station site in every network is hard to obtain.

The Capacity Model estimates the cell radius for each type area, based on the corresponding radio base station density ($\#RBSs/Km^2$) provided by the Coverage Model. Here, $\#RBSs$ is the number of radio base stations and Km^2 refers to the total geographical area covered with service by these radio base stations, $A_{covered}$. The radio base station density can be rewritten as $RBS_{density} = \#RBSs/A_{covered}$.

The total area covered is $A_{covered} = A_{RBS} \cdot \#RBSs$, where A_{RBS} is the radio base station coverage area. Then, the radio base station coverage area can be expressed in terms of the radio base station density:

$$A_{RBS} = \frac{1}{RBS_{density}} \tag{A.1}$$

When the cells are uniformly distributed in an hexagonal layout, the area covered by one radio base station can be approximated by

$$A_{RBS} = 3 \cdot A_{RegularHexagon}, \tag{A.2}$$

where $A_{RegularHexagon}$ is the regular hexagon's area. If L is the side of the hexagon and recalling that in a regular hexagon, the radius R is equal to its side L, then

$$A_{RegularHexagon} = \frac{3 \cdot \sqrt{3}}{2} \cdot R^2. \tag{A.3}$$

From equation A.1, A.2 and A.3 we finally obtain an expression for the cell radius:

$$R = \left(\frac{2}{9 \cdot \sqrt{3} \cdot RBS_{density}} \right)^{\frac{1}{2}}. \tag{A.4}$$

Appendix B

Glossary

2G - The common term for the second-generation mobile phone technologies, including GSM.

3G - The third generation mobile phone technologies that have improved support for data and multimedia services. WCDMA is one of the 3G standards.

3GPP - Third Generation Partnership Project is a technical standards group focusing on GSM, GPRS, EDGE, WCDMA, and related technologies.

ADSL - Asymmetric Digital Subscriber Line is a Broadband technology that operates over a normal telephone line, transforming it into a high-speed digital line that can be used for downloading information from the Internet or sharing information between offices. It is also an "always on" service and is charged at a flat rate. It is called "asymmetric" because it moves information more quickly to the computer than from the computer.

Always on - A connection to the Internet that is permanently available and ready for use. By contrast, a typical modem connection needs to be manually initiated each time one wish to uses it.

Band Size - Same as frequency bandwidth. Is a frequency range, usually specified by the number of hertz in a band or between upper and lower limiting frequencies. Alternatively, the frequency range that a device is capable of generating, handling, passing or allowing.

Best Effort - The type of service offered by a non-QoS-enabled packet switched network, and in particular by today's Internet. With best effort service, all packets are treated the same way with respect to forwarding priority and drop preference.

Bit Rate - Is the capacity characteristic of digital signals as defined by the number of bits (or bytes) per second that a channel will support. For example, a transmission facility that can support information exchange at the rate of 1 megabit per second (1 Mbps or 1,000,000 bits per second) delivers the same quantity of information, i.e., throughput, as a 1 kilobit per second (kbps or 1,000 bits per second) facility, but, in only 1/1000 of the time.

BLER - Block Error Rate. A ratio of the number of erroneous blocks to the total number of blocks received on a digital circuit. BLER is used for WCDMA performance requirements tests.

CAPEX - Capital Expenditures are funds used by a company to acquire or upgrade physical assets such as property, industrial buildings, or equipment. This type of outlay is made by companies to maintain or increase the scope of their operation. These expenditures can include everything from repairing a roof to building a brand new plant.

Carrier - Throughout this report, a *carrier* is used to denote a frequency band that is allotted to an *Operator* for use in radio communication. Carrier bandwidths may differ depending on the wireless technology in use. Warning: In other literature, a *carrier* is sometimes used to denote what we in this report call an *operator*, but we do not.

CDMA - Code Division Multiple Access is a digital wireless technology that works by converting speech into digital information, which is then transmitted as a radio signal over a wireless network. Using a unique code to distinguish each call, CDMA uses spectrum efficiently, enabling more people to share the airwaves simultaneously without static, cross-talk or interference.

Cell - The name of the geographical area covered by one sector of a base station using one carrier. A cell is the geographical area covered by a cellular telephone transmitter. The transmitter facility itself is called the cell site. The cell provided by a cell site can be from one mile to twenty miles in diameter, depending on terrain and transmission power.

Co-siting - Placing more than one base station at the same site; usually referred to when a 3G base station is using a 2G site. It is not the same as a shared network.

CS - Circuit Switched is a type of network in which a physical path is obtained for and dedicated to a single connection between two end-points in the network for the duration of the connection.

Downlink (DL) - Technical term for data transmission from the network to the subscriber or user terminal. The return channel, i.e. the reverse transmission direction, is referred to as an “uplink”. With asymmetric transmission methods, normally data rates are higher in the downlink direction than in the uplink direction. With symmetric transmission the data rates are the same in both directions.

Enhanced Uplink - An enhancement to WCDMA networks that provides higher data speeds in the uplink to support applications such as VPN access and large file transfers.

Erlangs - Erlang is an international dimension unit of the average traffic intensity of a facility during a period of time. One erlang of traffic is equivalent to a single user who uses a single resource 100% of the time.

GPRS - General Packet Radio Service is a packet-based wireless communication service that promises data rates from 56 up to 114 kbps and continuous connection to the Internet for mobile phone and computer users. The higher data rates will allow users to take part in video conferences and interact with multimedia Web sites and similar applications using mobile handheld devices as well as notebook computers. GPRS is based on Global System for Mobile (GSM) communication and will complement existing services such circuit-switched cellular phone connections and the Short Message Service (SMS).

GRAKE receiver - Generalized Rake receiver is a radio receiver having multiple receptors using offsets of a common spreading code to receive and combine several multipath time-delayed signals.

Greenfield operator - An operator that builds a completely new network.

GSM - Global System for Mobile communication is the worlds most widely used second generation mobile system. Used on the 900 MHz and 1800 MHz frequencies in Europe, Asia, and Australia, and the MHz 1900 frequency in America.

HS - Abbreviation for High Speed.

HSDPA - High Speed Downlink Packet Access. An enhancement to WCDMA networks that provides higher data speeds in the downlink to support applications such as VPN access, video downloads and large file transfers.

Iub - The interface between the RNC and the Node B in a 3G network.

Iur - The interface between RNCs in a 3G network.

Incumbent operator - An operator that already owns a 2G network.

kbps - Kilobits per second (thousands of bits per second). Is a measure of bandwidth (the amount of data that can flow in a given time) on a data transmission medium. Higher bandwidths are more conveniently expressed in megabits per second (Mbps, or millions of bits per second) and in gigabits per second (Gbps, or billions of bits per second).

Latency - Same as delay. It is a measure of the time it takes for a message to be transmitted across a network. The variance of the latency is also an important measure.

MoU - Minutes of Use, a term that is used to describe how many minutes an average subscriber will use (on average) telephony or video services during a certain period.

Node B - The term used for WCDMA radio base stations. It is also referred as to RBS through this document.

Operator - A company that delivers phone calls or data packets from customers to customers.

PS - Packet Switched describes the type of network in which relatively small units of data called packets are routed through a network based on the destination address contained within each packet. Breaking communication down into packets allows the same data path to be shared among many users in the network. This type of communication between sender and receiver is known as connectionless (rather than dedicated). Most traffic over the Internet uses packet switching and the Internet is basically a connectionless network.

PS Data - Packet Switched Data is the data transmitted from multiple users in individually addressed discrete packets. By using packet data, channels can be used for transmissions from multiple users, thereby improving efficiency.

QoS - Quality of service is the network's ability to give different treatment to traffic from different users or applications. Today's Internet does not offer QoS. QoS is specified in terms of one or more of the following parameters: bandwidth, delay, jitter, and loss.

R99 - Release 99 refers to the specifications for WCDMA technology defined by the 3rd Generation Partnership Project (3GPP) by the end of 1999. The first full release of the specifications are called “Release 99”, or just R99.

RAB - The Radio Access Bearer (RAB) is the entity responsible for transporting radio frames of an application over the access network in UMTS. The parameters of a RAB, namely the maximum bandwidth and the allowed frame sizes, can be configured according to the requirements of the application using it.

RAN - Radio Access Network is the portion of a mobile phone network that relates to the transmission or radio communications between the terminal device and the network base station.

RBS - Radio Base Station contains the transmit and receive technology and also the antennas to supply a cellular radio cell.

RNC - Radio Network Controller is the element which controls the Node Bs within a 3G network.

ROI - Return On Investment. The amount of profit (return) based on the amount of resources (funds) used to produce it.

Sector - The sector defines the area covered by an antenna of a base station. If the sector transmits using multiple carriers, multiple cells reside in that sector.

Shared network - A shared network is the term for a network that is shared by multiple operators. It is not uncommon for operators to build a shared network in rural areas, where coverage is needed but traffic is low. Not sharing infrastructure at these areas would lead to high investments but low revenues.

Site - The site literally refers to the physical location where a base-station and the accompanying antenna mast reside. In this report, the name site is used interchangeably with the term base station.

SMS - Short Message Service is a service for sending messages of up to 160 characters (224 characters if using a 5-bit mode) to mobile phones. SMS is similar to paging, however SMS messages do not require the mobile phone to be active and within range and will be held for a number of days until the phone is active and within range.

Throughput - Def. 1: The number of bits, characters, or blocks passing through a data communication system, or portion of that system. Note 1: Throughput may vary greatly from its theoretical maximum. Note 2: Throughput is expressed in data units per period of time; e.g., in the HSDPA, as kilobits per second.

Def. 2: The maximum capacity of a communications channel or system.

Uplink (UL) - Technical term for data transmission in the direction from the subscriber to the network, or rather back to the network. Also called back channel.

VBA - Visual Basic for Applications is the common (macro) programming language available for Office tools. It is a technology for developing client applications and integrating them with existing data and systems. VBA is based on the Microsoft Visual Basic.

WCDMA - Wideband Code Division Multiple Access. Wideband CDMA is a third-generation, CDMA-based wireless communication technology that offers enhanced voice and data capacity and higher data rates than previous, second-generation wireless technologies. It provides simultaneous support for a wide range of services with different characteristics on a common 5 MHz carrier.

Appendix C

Information Resources

During the span of this project, we had several meetings and interviews with several Ericsson's experts. The list of these interviews is presented bellow.

Name	**Role and Department**	**Date**
Alceu Corrocher	CE/EBS/HD/A/Q	September 27, 2005
Anette Borg	KI/EAB/PTN/T	*Continuously*
Birgitta Olin	KI/EAB/TBY/Y	September 28, 2005 and October 07, 2005
Claes Andersson L	KI/EAB/PTN/G	September 08, 2005
Fred Ersson	KI/EAB/PTN/G	September 12, 2005
Fredrik Gessler	Coach, KI/EAB/PV/N	*Continuously*
Jens Knutsson	KI/EAB/PV/N	June 27, 2005
Jonas Ericson	KI/EAB/Z/ND	September 26, 2005
Mats Ek O	KI/EAB/PTN/G	*Continuously*
Patrik Persson	KI/EAB/PDT/M	September 13, 2005
Patrik Regårdh	KI/EAB/DSM	August 22, 2005
Reinaldo Varani Junior	CE/EBS/HD/A/Q	September 13, 2005
Rene Summer	KI/EAB/PE/B	July 05, 2005
Roger Ekstrand	KI/EAB/PV/M	September 07, 2005
Sean Elliott	KI/EAB/PE/B	July 13, 2005
Svante Bergqvist	Orderer, KI/EAB/PE/B	*Continuously*
Tomas Sandin	KI/EAB/PV/N	October 03, 2005; November 18, 2005 and December 02, 2005
Wayne Hsiao	KI/EAB/PDV/N	October 10, 2005