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Service Forecast Sensitivity Analysis

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1 Introduction

1.1 Background

The estimation of demand has a central role in all business as enhancement of decision-making. This project focuses on the mobile services and applications demand monitoring and forecasting.

The mobile services are defined as all the services distributed throughout mobile networks and used with mobile devices. The mobile networks here refer to wide-area wireless networks (cellular networks), and the mobile devices are defined to be devices that have connection either directly or indirectly to mobile networks and are handheld size. Therefore, e.g. WLAN networks and laptop computers are excluded from the study. The mobile services and applications markets are modeled by the means of several characteristics. Number of subscribers, customer usage times and tariffs (etc) are examples of the characteristics defining these markets.

This study is the final report for the course Mat-2.177 Seminar in Operations Research. Nokia Mobile Phones is the client of this study.

1.2 Objectives and limitations

The main objective of the study is to *analyze and improve the mobile services and applications monitoring and forecasting model through sensitivity analysis*. It was seen feasible to divide the main objective to five sub targets to fully cope with the main purpose of the study. Therefore, in addition to its main objective the study also intends to:

- Identify the most critical variables from the model, that is, inputs that cause largest fluctuations in the outputs in terms of each year, market, and also in long-term basis.
- Identify the most insignificant variables from the model, that is, inputs that cause only weak and thus meaningless fluctuations in the outputs in terms of each year, market, and also in long-term basis.
- Examination of the magnitudes of changes caused main effects in critical input variables in each year, market, as well as in long-term basis.
- Find out the magnitude of changes caused by interaction effects of predefined critical variables.
- Identify weaknesses in the model and recommend improvements to the model.

- Determine instructions for future sensitivity analysis and most efficient usage of the forecasting model

First of all, the project is limited to simulation of a model supplied by the client. The variables of the model were covered from project group for confidence reasons. Therefore the variables are discussed in this report with dummy names, such as service 1.1 and market region 1. The model was also simplified by NMP and only three of ten market regions were under study. Only the usage and subscribe revenues were examined, and the revenues from traffic were excluded from the model.

The project is methodologically limited to 2^k experiments and Monte Carlo -simulations with @risk software.

1.3 Timetable and Resources

The starting date for the project was 17.1.2003. After first meet with the client the project plan was formed and presented (14.2). The progress (interim) report was presented a month later, 14.3. The final version of the project report was handed to the client and to course personnel 25.4 and finally presented 2.5

The main resources of the project were, in addition to the project team members, course personnel and the client. The client provided the modelling tool, which was built on Microsoft Excel platform and it used Excel spreadsheet calculation and macro language procedures.

1.4 Structure and scope

Chapter 2 starts with methodology, in which experiment design, sensitivity and regression analysis and statistics theory is presented. Chapter 3 represents the market model, @risk simulation software and how the testing and simulation were done. In the chapter 4 the results are presented, and the fifth chapter 5 concludes. The appendixes contain simulation results and a review of the project.

2 Methodology

2.1 Sensitivity Analysis

Sensitivity analysis is used to ascertain how a given model output depends upon the input parameters. This is an important method for checking the quality of a given model, as well as a powerful tool for checking the robustness and reliability of its analysis.

Sensitivity Analysis is the study of how the variation in the output of a model can be apportioned, qualitatively or quantitatively, to different sources of variation. Sensitivity analysis aims to ascertain how the model depends upon the information fed into it, upon its structure and upon the framing assumptions made to build it. This information can be invaluable, as

- Different level of acceptance (by the decision-makers and stakeholders) may be attached to different types of uncertainty.
- Different uncertainties impact differently on the reliability, the robustness and the efficiency of the model.

The latter one was our objective.

Originally, sensitivity analysis was created to deal simply with uncertainties in the input variables and model parameters. Over the course of time the ideas have been extended to incorporate model conceptual uncertainty, i.e. uncertainty in model structures, assumptions and specifications. As a whole, sensitivity analysis is used to increase the confidence in the model and its predictions, by providing an understanding of how the model response variables respond to changes in the inputs, be they data used to calibrate it, model structures, or factors, i.e. the model independent variables.

2.2 Experiment Design

Experiments are used to discover something about a particular process or system. The goal of experimental design, by contrast, is to achieve these discoveries as efficiently and properly as possible. The objective in the design is to provide results from the

experiments that have statistically good qualities and are the most suitable for the situation: simple to perform and analyse, in other words, robust.

The principle guidelines for performing experiments are

1. Recognition and statement of the problem
2. Choice of factors, levels and ranges
3. Selection of the response variable
4. Choice of experimental design
5. Performing the experiment
6. Statistical analysis of the data
7. Conclusion and recommendations

2.3 2^k Factorial Design

Many experiments involve the study of the effects of two or more factors of the system. In general, factorial designs are most efficient for this type of experiment. Factorial design means that in each complete trial or replication of the experiment all possible combinations of the levels of the factors are investigated. The effect of a factor is defined to be the change in response produced by a change in the level of the factor. This frequency is called a main effect because it refers to the primary factors of interest in the experiment.

Factorial designs are widely used in experiments involving several factors where it is necessary to study the joint – mutual – effect of the factors on a response. It is common that factors of the system have interactions between each other. This means that the other factors levels have effect for the examined factor's effect.

In the two-factor factorial design the both factors have many levels to be examined. This leads to numerous tests that give in result of the nature of the interaction between the two chosen variables. In the more general experimental designs, 2^k factorial designs, it is normal to assume that the response is approximately linear over the range of the factors to be investigated. This allows to use just two levels of the factors, normally referred by “+” and “–” levels. In linear models the two levels are normally maximum and minimum

values of the factor's range. Naturally this simplifies the experiment considerably and allows perform more complicated experiments involving several variables.

The 2^k design is particularly useful in the early stages of experimental work, when there are likely to be many factors to be investigated. It provides the smallest number of runs with which k factors can be studied in a complete factorial design. In a two-level factorial design, it is possible to define the average effect of a factor as the change in response produced by a change in the level of that factor averaged over the levels of the other factor.

Normally the notation in the 2^k design goes as following. The effect of different factors is denoted by a capital Latin letter. Thus "a" refers to the effect of factor A and "AB" refers to the AB interaction. The treatment combinations, where the factors are either low or high, are denoted usually in lowercase letters. Marking the high level factors by the lowercase letters and the low level factors by the absence of the corresponding letter does this. The Table 1 explains the denoting for a 2^2 design.

Effects	(1)	a	b	Ab
A	-	+	-	+
B	-	-	+	+
AB	+	-	-	+

Table 1: 2^k factor experiment example

The effects then can be calculated by adding and subtracting the outputs of the different treatment combinations as shown in the table x. Thus the effect of the factor AB can be calculated as following

$$AB = \left(\frac{1}{2}\right) \left[(ab - b) - (a - (1)) \right] = \left(\frac{1}{2}\right) \left[ab + (1) - a - b \right], \quad (1)$$

where the $\frac{1}{2}$ comes from simply averaging the effects. As the size of the 2^k designs grow exponentially – really fast – the size of the experiments may explode easily. There are numerous ways of diminishing the size of the experiments. This can be done for example by blocking the experiment or reducing the model examined, which in spite of all affects the quality of the experiments. [1]

2.4 Regression Analysis

In general suppose that there is a single depended variable or response y that depends on k independent or regression variables, for example x_1, x_2, \dots, x_k . A mathematical model called a regression model characterizes the relationship between these variables. The regression model is fit to a set of sample data.

In the linear regression model, the dependent variable is assumed to be a linear function of one or more independent variables plus an error introduced to account for all other factors:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 + \dots + \beta_n x_n + \varepsilon \quad (2)$$

In the above regression equation, y is the dependent variable, x_1, \dots, x_n are the independent *or* regression variables, and ε is the disturbance or error term. The goal of regression analysis is to obtain estimates of the unknown parameters β_0, \dots, β_n , which indicate how a change in one of the independent variables affects the values taken by the dependent variable.

The (3) is called a multiple linear regression model with n regression coefficients. This model defines describes a plane in the n -dimensional x_1, \dots, x_n space. The parameter β_0 defines the intercept of the plane. The β_0, \dots, β_n are called sometimes as partial regression coefficients, because β_i measures the expected change in y per unit change in x_i when other x :s are held constant.

The method of least squares is typically used to estimate the regression coefficients in a multiple linear regression model. Suppose that $n > k$ observations on the response variable are available, say y_1, y_2, \dots, y_n . Along with each observed response y_i we will have an observation on each regressor variable and let x_{ij} denote the i th observation or level of variable x_j . The error term ε is supposed to have $E(\varepsilon)=0$ and $V(\varepsilon)=\sigma^2$ and that the $\{\varepsilon_i\}$ are uncorrelated random variables.

We may write the model equation in terms of the observations as

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_n x_{in} + \varepsilon_i = \beta_0 + \sum_{j=1}^k \beta_j x_{ij} + \varepsilon_i \quad (3)$$

The method of least squares chooses the β 's so that the sum of the squares of errors ε_j is minimized. The least squares function is then

$$L = \sum_{i=1}^n \varepsilon_i^2 = \sum_{i=1}^n \left(y_i - \beta_0 - \sum_{j=1}^k \beta_j x_{ij} \right)^2. \quad (4)$$

The function L is to be minimized with the respect to β_0, \dots, β_n . The least squares estimators, say $\hat{\beta}_0, \dots, \hat{\beta}_n$ must satisfy

$$\frac{\partial L}{\partial \beta_0} \Big|_{\beta_0, \beta_1, \dots, \beta_k} = -2 \sum_{i=1}^n \left(y_i - \hat{\beta}_0 - \sum_{j=1}^k \hat{\beta}_j x_{ij} \right) = 0 \quad (5)$$

and

$$\frac{\partial L}{\partial \beta_j} \Big|_{\beta_0, \beta_1, \dots, \beta_k} = -2 \sum_{i=1}^n \left(y_i - \hat{\beta}_0 - \sum_{j=1}^k \hat{\beta}_j x_{ij} \right) x_{ij} = 0, \quad (6)$$

where $i = 1, 2, \dots, n$ and $j = 1, 2, \dots, k$.

From these equations it is easy calculate the wanted coefficients. This is done by obtaining these equations to a $p = k + 1$ number of equations, one for each of the unknown regression coefficients. The solution to these normal equations will be the least squares estimators of the regression coefficients.[1]

2.5 Statistics – Central Limit Theorem

If $y_1, y_2, y_3, \dots, y_n$ is a sequence of n independent and identically distributed random variables with $E(y_i) = \mu$ and $V(y_i) = \sigma^2$ (both μ and σ finite) and $x = y_1 + y_2 + \dots + y_n$, then

$$z_n = \frac{x - n\mu}{\sqrt{n\sigma^2}} \quad (7)$$

has an approximate $N(0,1)$ distribution in the sense that, if $F_n(z)$ is the distribution function of z_n and $\Phi(z)$ is the distribution of the $N(0,1)$ random variable, then

$$\lim_{n \rightarrow \infty} \left[\frac{F_n(z)}{\Phi(z)} \right] = 1. \quad (8)$$

This result states essentially that the sum of n independent and identically distributed random variables is approximately normally distributed. In many cases this approximation

is good for very small n , say $n < 10$, whereas in other cases large n is required, say $n > 100$.

In general the central limit theorem says that sum of a large amount of anyhow distributed variables is approximately normally distributed. This is very useful when it comes to inference. For example, it allows using hypothesis tests which assume normality even if the data is non-normal. [1, 2]

- **Preferred way of using:** The preferred enabler that is used to for a service. The variable varies in time, region, service and enabler. The preferred way of using is assumed to be same in different end-user segments.
- **Usage tariff:** The tariff paid buy a user for a single use of a service. Variable varies in time, region and service.
- **Subscription tariff:** The subscription tariffs paid buy a user for use of a service in year. Variable varies in time, region and service.

3.2 Simulation with @Risk software

@RISK 4.5 is a Monte Carlo simulation add-in for Microsoft Excel. Sensitivity analysis means that we study the effects of small changes in individual variables in the model. Using @RISK for Sensitivity Analysis encompass next steps:

- *Identifying Uncertainty* — in variables in Excel worksheet model and specifying their possible values with probability distributions, and identifying the uncertain worksheet results (outputs) we want analyzed
- *Analyzing the Model Sensitivity with Simulation* — to determine how sensitive the model outputs are for different input values

@RISK uses simulation, sometimes called Monte Carlo simulation, to do a Sensitivity Analysis. Simulation in this sense refers to a method whereby the distribution of possible outcomes is generated by letting a computer recalculate a worksheet over and over again, each time using different randomly selected sets of values for the probability distributions in cell values and formulas. In effect, the computer is trying all valid combinations of the values of input variables to simulate all possible outcomes. By using @risk and its Monte Carlo simulation, the model becomes of course undetermined.

Sensitivity analyses in @RISK performed on the output variables and their associated inputs use either multivariate stepwise regression or a rank order correlation. We used multivariate stepwise regression. In the regression analysis, the coefficients calculated for each input variable measure the sensitivity of the output to that particular input distribution. The coefficients listed in the @RISK sensitivity report are normalized

regression coefficients associated with each input. A regression value of 0 indicates that there is no significant relationship between the input and the output, while a regression value of 1 or -1 indicates a 1 or -1 standard deviation change in the output for a 1 standard deviation change in the input. [3]

The output variable we monitored was Total Revenue. The mutual effects were tested with a two-factor factorial design so that both factors were given a certain distribution in a certain – low or high – level of its given range. We meant to perform the total of four simulations of this kind per pair for each three market for each year. Due to trial program's expiration, the test for the market 1 and 2 were performed just for years 2003 and 2007. Anyhow the tests were done like this: one test where the variables were given the low levels, one with high levels and two where the levels were either low or high.

3.3 Simulations

The @risk simulations were done in two separate groups and phases. The purpose of the first set of simulations was to identify critical input variables (main effects) from the model. The critical variables were those which fluctuation had strong impact on the total market revenue. These simulations were done for each year and market separately. A long run simulation was done only for the critical variables in each market.

The purpose of the second set of simulations was to identify the mutual impacts (interactions) between important input variables. The we selected these “important” input variables with the client. These variables were subscribers, usage, and tariffs. The mutual impact simulations were done for each year and each market.

In the critical variable simulations, the input variables were considered to be random variables and a random distribution was set to each input variable. In one simulation round, a random number was drawn from each distribution and then the market total revenue was calculated from them. In the first simulation phase (main effects), 5000 iterations were used for markets 1 and 3 as the market 2 was simulated with only 1000 iterations. The mutual impact (interactions) simulations contained 500 rounds. The standardized regression coefficients for the sensitivity analysis were calculated from the simulation results.

The interactions between variable groups were examined in pairs. These pairs were introduced by the client and included: 1) Usage Times vs. Usage Tariffs, 2) Subscribers vs. Usage Times. All the three regions were analysed independently. All the market regions were planned to analyse in seven years period (2001 – 2007), but due to trial program's expiration, the test for the market 1 and 2 were performed just for years 2003 and 2007. For mutual effect analysis we carried out four simulations per market annually. We were

interested about mutual effect of usage times and subscribers. As we were given annual limits for every variable, for gaining information about their mutual effects we ran simulations with their extreme points within these limits. In other words, these cases were:

- Number of subscribers and usage times low, 70% of the expected value
- Number of subscribers low, 70% of the expected value
Usage times high, 130% of the expected value
- Number of subscribers high, 130% of the expected value
Usage times high, 70% of the expected value
- Number of subscribers and usage times high, 130% of the expected value

The percents are referring to the mean of the variable. As mentioned before, we simulated all the variables and analysed their regression for the output, total revenue.

The distribution used for different input variables in all simulations were following:

- **Subscribers**

A normal distribution was used for the subscribers. The subscriber amounts are forecast with a time-series model and the model error were usually assumed to be normal. The use of normal distribution can be justified also with central limit theorem. The normal distribution mean value was the subscriber forecast value and the standard deviation was assumed to be five per cent from subscriber amount in years 2001-2004 and ten per cent in years 2005-2007. These figures were adopted from the client.

- **End-User split to Segments**

The end-user split to segment is based on information received from customers and insight of analysts. Therefore were decided to use triangular distribution for the end-user segments. All three end-user segments were assumed to be random variables in order to get regression coefficient for each segment and therefore the sum of the end-user segments was not exactly 100 per cent. This was not seen as a problem, because the end-user segments were only used to calculate the amount of end-users in each segment from total subscriber amount. Therefore if the end-user segment sum was over 100 per cent it corresponded to little higher total subscriber amount. The triangular distribution mean value was the actual end-user segment split and the minimum and maximum values were two per cent unit from it.

- **Enabler penetration**

The enabler penetration was a forecast by the client as the subscriber amount. The client provided the fluctuation ranges for the enabler penetration, which were estimates from analysts. Therefore we used triangular distribution based on the received range estimates. Triangular distribution was used for the enabler 2 penetration variable with min-mean-max values 0.85-0.9-0.95 and enabler 13 with 0.65-0.7-0.75, since the client did not provide them.

- **Active users of potential users**

The active user per cent from potential users are based on customer insight and market knowledge. Triangular distribution was also used for active users per cent, since we estimated the variable range ourselves. The use of normal distribution could have been used instead. The triangular distribution min-mean-max values were set 95%-100%-105% from forecast value in years 2001-2004 and 90%-100%-110% in years 2005-2007.

- **Usage times**

The usage times are also forecasted based on end-user insight and market knowledge. The usage times are mean of the user segment usage and therefore it was assumed to be normally distributed. The normal distribution mean value was the forecast value and the standard deviation was assumed to 5 per cent from forecast value for services 1.2-3.10 in years 2001-2004 and 10 per cent in years 2005-2007. The standard deviation for services 5.1-6.1 was 10 per cent in years 2001-2004 and 20 per cent in years 2005-2007.

- **Preferred way of using**

The preferred way of using forecasts are based on customer insight and market knowledge. The preferred way of using variables were assumed to be constant, since our knowledge on the variables was very poor and they only effect which enabler user is using.

- **Tariff**

The tariff input variables are based on market knowledge. The tariffs are average values of the all the tariffs in the market and therefore they were assumed to be normally distributed. The use of normal distribution was justified central limit theorem. The mean value of the distribution was set to actual forecast value. The distribution standard deviation was set to 5 per cent in service 1.1-3.10 in years 2001-2004 and 10 per cent in years 2005-2007. The standard deviation was 10 per cent for services 5.1-6.1 in years 2001-2004 and 20 per cent in years 2005-2007

10 Appendix D –Project Review

10.1 Objective review

The main objective of the project was formulated *to analyze and improve the mobile services and applications monitoring and forecasting model through sensitivity analysis*. The main objective was divided into sublevel objectives. The project main objective and sublevel objectives in overall were met only adequately.

- *Identification of the most critical input variables from the model in terms of each year, market, and also in long-term basis.*

The critical variable identification was carried out with @risk simulation. The regression coefficients were calculated from simulation results. Most of the input variable distributions were selected on poor argumentation, since the actual variables were unknown and so was their forecast method. Normal distribution seemed logical for unknown distribution and triangular for expert estimates. The actual simulation and critical variable identification from result were done thoroughly. Therefore this objective was meet very well. The long-term analysis was proved to be pointless.

- *Identification of the most insignificant variables from the model in terms of each year, market, and also in long-term basis.*

The results of the simulations showed most of the variables to have very little effect on the market revenue, and only few variables were very significant. The insignificant variables were not listed explicitly, since there were so many of them (dozens). Altogether the objective was meet well.

- *Examination of the magnitudes of changes caused by critical input variables in each year, market, as well as in long-term basis.*

The regression coefficients of the input variables were calculated for the significant variables, but the effects of change in variables were not analyzed further because of the lack of time. Therefore this objective was meet poorly.

- *Find out the magnitude of changes caused by interaction effects of predefined input variables.*

The mutual effects were identified from second round of simulations. The simulations were designed based on 2^k Factorial experiment designs. Same kinds of distributions were used as in the critical variables simulations and therefore more time should have been used to justify the input variable distribution. The simulations were done in adequate way and the results were analysed thoroughly. This objective was met well.

- *Identify weaknesses in the model and recommend improvements to the model.*

The present model and grounds for it remained somewhat unclear to our project team. By this I mean the actual input variables and model parameters, which were all presented to us with dummy names, such as service 1.1 or market 1, instead of their real names. Although the actual functionality of the model and excel tool became very familiar to the project team. We recognized some weaknesses in the model, such as long-term analysis and lack of history effects, and gave some ideas, such as new model service approach and elimination of unnecessary variables, which could improve the model. The objective was met in adequate way.

- *Determine instructions for future sensitivity analysis and most efficient usage of the forecasting model.*

The future instructions were design purely for @risk simulations. The @risk was found very useful tool for the model testing and sensitivity analysis. The instruction focused on the selection of the input variables distributions and simulation design. The instruction should have been more general than sensitivity analysis with @risk software and at least other possible ways to sensitivity analysis could have been recommended. The objective was still met adequately.

10.2 ACTIONS AND TASKS REVIEW

The objectives were originally approached with five stages action plan. The first two stages learn functionality of the mobile market model and learn theory behind sensitivity analysis, were done in sufficient way. The theory of sensitivity analysis was not shared among the project team as well as it could have been done, which might have caused some problems. The next two stages, identification of critical and insignificant variables and in-depth sensitivity analysis, were revised in the interim report and changed to more detailed stages. These were the understanding of @risk software, carrying out a market, yearly and long-term sensitivity analysis, carrying out interaction effect sensitivity analysis

and result analysis. These actions were done in somewhat good manner despite some difficulties with @risk software and computers. The final stage was the documentation of the project, which was carried out with distinction regarding strong conflict on the matter between project team members.

The original idea was that the sensitivity analysis tool would be implemented with visual basic. This was found unnecessary during the project, since the project team learned about @risk software from NMP. The @risk was found to be very efficient and good tool for sensitivity analysis. This change caused large changes in the task list and in work estimates in the middle of the project. The work amount was originally overestimated. The actual work done during the first half of the project was less than half from the estimates. The tasks to be done and work estimates for them were updated in the middle of the project. The updated work estimates were much better than the original ones, but they were still exceeded by few hours.

ID	Task Name	Work	Actual Work
1	Project plan	16 hrs	12 hrs
2	Theory study: Design and Analysis of Ex	48 hrs	20 hrs
3	Practical Study: Excel-model	32 hrs	13 hrs
4	Theory study: Visual Basic programming	32 hrs	0 hrs
5	Project meeting 1 - Study review	15 hrs	10 hrs
6	Test Plan 1 - Critical variable identificati	32 hrs	8 hrs
7	VB programming 1	24 hrs	10 hrs
8	Testing 1	8 hrs	7 hrs
9	Test result analysis 1	32 hrs	4 hrs
10	Project meeting 2 - Result review 1	10 hrs	4 hrs
11	Progress Report	32 hrs	6 hrs

Table 13: Work estimates and work done in the first half

ID	Task Name	Work	Actual Work	Overtime
1	@Risk studying	4 hrs	4 hrs	5 hrs
2	Test plan - critical variables	4 hrs	4 hrs	1 hrs
3	Test plan - mutual effects	4 hrs	4 hrs	0 hrs
4	Testing - critical variables	10 hrs	10 hrs	6 hrs
5	Testing - mutual effects	4 hrs	4 hrs	4 hrs
6	Project meeting 3 - Result review	10 hrs	10 hrs	2 hrs
7	Additional testing	10 hrs	6 hrs	0 hrs
8	Final report	60 hrs	60 hrs	3 hrs
9	Project management	20 hrs	20 hrs	0 hrs

Table 14: Work estimate and work done in the second half

10.3 SCHEDULE REVIEW

The project was originally scheduled to proceed gradually in two or three week rounds. Each group member had to finish his action in each round. During the initial testing we faced some problem with poor test and action planning, which later on changed the planned actions by introducing @risk software. These problems caused a weeks delay in schedule. The project schedule was also brought forward by a week in the middle of the project, since the project leader was absent during the last possible week. The second half of the project proceeded in new schedule, but again some group member faced unexpected problem in testing, which caused some delays during the last days of the project. The some project members failed to meet the internal deadlines for project documentation, which caused severe schedule problems and overtime work in the last week of the project. An arranged meeting with the NMP was almost cancelled, since the documentation of the project was not finished in time. The purpose of the meeting was to analyse first version of the documentation, but we finally managed to put a simple result document together before the meeting. The tightened schedule and delays caused some quality problems. The mutual effect analysis could not be done as thoroughly as planned for markets 1 and 2, and the effects of change in input were not analyzes as well as originally planned. Nevertheless we finished the project one week earlier than originally planned.

10.4 MANAGEMENT REVIEW

The project management main purpose was to be in contact with the customer (NMP) and course personnel (HUT). The first delay occurred mainly because the project manager was not able to gain all the necessary information from NMP in time. Besides this the project manager stayed in regular contact with NMP. The project manager also wrote the project plan, interim report and project review mainly by himself. Comments, corrections and information were received from other project members. These project reports were done very well.

The project manager did not lead the project group firmly enough, which might have caused some problems. The project manager assumed that each individual would be able to do his task independently, but this was not always the case. The project manager should have watched more closely, that the arrangements and tasks were understood properly. Some of the project member had difficulties fulfilling their task and

understanding what was happening and why and what to do. The project manager was Juha Koskenkylä.

10.5 RISKS

Three risks were listed in the original plan and two more was introduced in the interim report. The possible risks were identified excellently, but the preparations were not done adequately. One of the risks became absent in the middle of the project. All other risks caused problems in the project.

- *Nokia dedication.*

All the necessary information was not received from NMP in time, which caused schedule delay in the first half of the project. No problems were encountered during the second half of project. These problems with Nokia could have been avoided with more aggressive communication.

- *Project member dedication and cooperation*

The project team communication was quite poor. The team member did not forewarn others properly when they occurred problem or could not keep up with the schedule. The result and documentation done was just sent late. Some members contacted project manager when they faced a problem or could not finish their task in time, which was very good and expected behaviour from everyone. The group member had severe disagreements on the depth and level of detail in the documentation. Some of the problems occurred during the initial testing and later on simulation. The project manager also felt that some of the project group members did not respect internal deadlines and the level of dedication was quite low, which resulted some problem in documentation, but finally documentation was pulled together with flying colours. This was seen as a problem based on the past experiment and the best way to avoid these problems is to work with familiar people.

- *Project schedule*

The project schedule was seen as a quality risk in the second half, because of one week delay during the first half and earlier deadline. More delay occurred in the documentation stage, which caused internal conflicts. The schedule problems could have been probably avoided with better group member dedication and communication.

- Visual Basic programming.

The sensitivity tool was not implemented with VB and therefore no VB programming was needed in the project.

- @risk software

The sensitivity analysis was finally done with @risk software, which also caused some problems. The project group did not had access to licensed a version of @risk and therefore the @risk software could be used only during a ten day time window. The trial version that was used generated “Trial Version” text in every image, which caused overtime work, since all the images had to be transferred into Excel. One of the project group members was not able to reopen his simulation results and one accidentally saved other simulation results over the last one. These accidents caused some overtime work and therefore all of the simulation results were not as thorough as they could have been. Problems with @risk software could have been possibly avoided with a coordinated @risk instructions and better communications. The group members should have counseled each other more with the software.