

Application of an Adapted MCDA Using UCN's

Werner A Pretorius
E.Eng (Electronic & Computer)

**Thesis submitted In Partial Fulfilment of the Requirements for
the Degree**

Magister Engineering (Electronic & Computer)

School of Electric and Electronic Engineering

at the

North-West University, Potchefstroom Campus

Supervisor: Prof A.S.J. Helberg

2004



Potchefstroomkampus

EXECUTIVE SUMMARY

In this dissertation an adapted MCDA (Multiple-Criteria Decision Aid) evaluation process/method is presented. In this adapted process/method, evaluation techniques that are intended for the detailed evaluation of subsections of a system are used for evaluation from a higher point of view (a broader evaluation). Due to the assumptions made in MCDA it has a number of shortcomings (e.g. can only handle criteria that are certain).

UCN's (Uncertain Criteria Networks) are used to make an adaptation on the MCDA method to enable the method to cope with some of its shortcomings (to handle certain and uncertain criteria). The techniques that are implemented in the MCDA method are NWS (Numerical Weighted Sum) and QWS (Qualitative Weighted Sum).

The implementation of this evaluation process is focused specifically on the evaluation of the functionality of the field units, which can be used in a WebForce automation dispatching system of Telkom. The evaluation of three field units in three different classes (PDA, cell phone and laptop) is done as a case study.

As a result of the sensitivity analyses that are conducted on the standard MCDA and the MCDA that are adapted with the UCN method, the PDA seems to be the best choice for a field unit for the new WebForce dispatching automation project.

In summary, the value of the project can be divided into two aspects:

- The creation of an evaluation method (MCDA with UCN incorporated) that is able to cope with certain and uncertain criteria.
- The Telkom's WebForce task dispatching automation upgrade project was used as a case study for the application of the evaluation model. The evaluation is focused specifically on the field units that must be used in the new system, it is concluded that the PDA seems to be the best option for the Telkom case study.



UITTREKSEL

In die skripsie word 'n aangepasde MCDA ("Multiple-Criteria Decision Aid") evaluasie proses/metode aangebied. In die aangepasde proses/metode word evaluasie tegnieke wat bedoel is vir gedetailleerde evaluasie toegepas op n evaluasie op n hoër vlak. As gevolg van aannames wat gemaak word deur die MCDA tegniek is daar tekortkominge (kan slegs kriteria hanteer wat seker is).

UCN's ("Uncertain Criteria Networks") word gebruik om die MCDA aan te pas om die metode in staat te stel om kriteria wat seker en kriteria wat onseker is te hanteer. Die tegnieke wat toegepas word in die evaluasie is NWS ("Numerical Weighted Sum") en QWS ("Qualitative Weighted Sum").

Die implementering van die aangepasde MCDA evaluasie metode fokus spesifiek op die evaluasie van die funksionaliteit van veld eenhede wat gebruik word vir die Telkom WebForce sisteem. Die evaluasie van drie klasse veld eenhede (PDA, Selfone en draagbare rekenaars) word gedoen.

As resultate word daar sensitiwiteit analyses op die MCDA en die UCN dele van die model gedoen. Uit die analyses kan mens aflei dat die PDA die beste keuse is vir die Telkom gevallestudie.

In samevatting, die waarde van die projek kan opgedeel word in twee dele:

- Die ontwikkeling van n evaluasie model (MCDA wat aangepas is met UCN) wat sekere en onseker kriteria kan hanteer.
- Die Telkom se "WebForce" stelsel opgradering projek was gebruik as n gevalle studie vir die evaluasie model. Die evaluasie fokus op die funksionele evaluasie van die drie klasse veld eenhede, as 'n konklusie word die PDA voorgestel as die beste opsie vir Telkom se stelsel.



TABLE OF CONTENTS

Executive Summary	i
Uittreksel.....	ii
Table of Contents	iii
List of Figures.....	vi
List of Tables	ix
CHAPTER ONE	1
1 Introduction.....	1
1.1 WebForce Background: Proposed System Upgrade.....	2
1.2 Problem Statement	3
1.3 Research Approach	4
1.4 Research Methodology	4
1.5 Motivation.....	9
1.6 Past/Related Studies.....	9
1.7 Beneficiaries of this Research.....	10
1.8 Conclusion	11
CHAPTER TWO	12
2 GPRS Literature Survey	12
2.1 GSM/GPRS Architecture Survey	13
2.2 Future Network Architecture	16
2.3 Short Range Communication Overview	17
2.4 Conclusion	19
CHAPTER THREE	20
3 Evaluation Literature Survey	20
3.1 Evaluation Techniques and Methods.....	21
3.2 Execution of methodology (MCDA) [19].....	22
3.3 Execution of Technique (Weighted Sum).....	27



3.4	Conclusion	30
CHAPTER FOUR.....		31
4	Evaluation Process Creation.....	31
4.1	Application of Standard MCDA Methodology to a Case Study [19]	32
4.2	Adapting the MCDA Method	40
4.3	Implementing a UCN model in MCDA.....	50
4.4	In summary this method consists of the following:	51
4.5	Evaluation Process Conclusion.....	52
CHAPTER FIVE		54
5	Evaluation Phase.....	54
5.1	Experimental setup conditions.....	55
5.2	UCN Sensitivity	55
5.3	MCDA Level-1 Sensitivity	59
5.4	MCDA Level – 2 Sensitivity	68
5.5	MCDA Single Criteria Sensitivity (on final score).....	86
5.6	MCDA Single Criteria Sensitivity (on “one level up” score).....	91
5.7	Conclusion	98
CHAPTER SIX		99
6	Conclusion	99
6.1	Background Summary	100
6.2	GPRS Survey Summary.....	100
6.3	MCDA Survey Summary.....	100
6.4	Evaluation Process Summary	101
6.5	Sensitivity Analysis Conclusion	102
6.6	Future work.....	104
6.7	“In a Nutshell”	104
References.....		105
Appendix A : Acronyms		107
Appendix B : Step 3 – Evaluation Attribute Tree		110
Appendix C : Step 4, 5 – Summary		112
C.1	Process Capability.....	112



C.2	Connection Capability	114
C.3	Portability.....	115
C.4	Initial Cost.....	115
C.5	Connection cost.....	116
C.6	Usage Cost	117
C.7	Summary	117
Appendix D : Step 7 – Aggregation Method.....		118
D.1	Level 3 Aggregation algorithms	118
D.2	Level 2 Aggregation algorithms	119
D.3	Level 1 Aggregation algorithm.....	119
Appendix E : Step 3 – Criteria Definition/Measurement Score.....		120
E.1	Experimental setup conditions	120
E.2	Example for determining of criteria boundaries	120
E.3	Specification - Processing Capability	122
E.4	Specification - Connection Capability	139
E.5	Specification - Portability	145
E.6	Cost: Initial Cost	154
E.7	Cost: Connection Cost	154
E.8	Cost: Usage Cost.....	154
E.9	Conclusion	155
Appendix F : Sensitivity Analyses.....		156
F.1	MCDA Single Criteria Sensitivity (on final score).....	156
F.2	Conclusion MCDA Single Criteria Sensitivity (on final score)	161
F.3	MCDA Single Criteria Sensitivity (on “one level up” score).....	161
F.4	Conclusion of MCDA Single Criteria Sensitivity (on one level up score)	170



LIST OF FIGURES

Figure 1-1: New WebForce Access Technology	2
Figure 1-2: Phases of Evaluation Process	5
Figure 3-1: Key MCDA concepts summarized	26
Figure 4-1: Field force dispatching system.....	32
Figure 4-2: Evaluation tree of case study	34
Figure 4-3: Example for determining boundaries.....	37
Figure 4-4: Definition of system usability	40
Figure 4-5: UCN for predicting the uncertain criteria in case study.....	43
Figure 4-6: UCN - Write Delay node	46
Figure 4-7: UCN - Read Delay node	47
Figure 4-8: UCN - Text Usability	48
Figure 4-9: UCN - Graphic Usability	49
Figure 4-10: UCN - Unit Usability	50
Figure 4-11: How the UCN approach fits into MCDA.....	50
Figure 5-1: UCN (Usability) Sensitivity – Cell Phone	56
Figure 5-2: UCN (Usability) Sensitivity – PDA.....	56
Figure 5-3: UCN (Usability) Sensitivity – Laptop	56
Figure 5-4: UCN (Usability) Sensitivity.....	58
Figure 5-5: MCDA Level-1 (Specification and Cost) Sensitivity – Cell Phone.....	61
Figure 5-6: MCDA Level-1 (Specification and Cost) Sensitivity – PDA	61
Figure 5-7 : MCDA Level-1 (Specification and Cost) Sensitivity – Laptop.....	62
Figure 5-8: MCDA Level-1 (Specification and Usability) Sensitivity – Cell Phone ..	63
Figure 5-9: MCDA Level-1 (Specification and Usability) Sensitivity – PDA.....	63
Figure 5-10: MCDA Level-1 (Specification and Usability) Sensitivity – Laptop.....	63
Figure 5-11: MCDA Level-1 (Cost and Usability) Sensitivity – Cell Phone.....	66
Figure 5-12: MCDA Level-1 (Cost and Usability) Sensitivity – PDA.....	66
Figure 5-13: MCDA Level-1 (Cost and Usability) Sensitivity – Laptop	66
Figure 5-14: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – Cell Phone.....	69



Figure 5-15: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – PDA	69
Figure 5-16: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – Laptop	70
Figure 5-17: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – Cell Phone.....	72
Figure 5-18: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – PDA	72
Figure 5-19: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – Laptop	72
Figure 5-20: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity – Cell Phone.....	76
Figure 5-21: MCDA Level-2 (Specification – Connection Capability and Portability) Sensitivity – PDA	76
Figure 5-22: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity – Laptop	76
Figure 5-23: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity – Cell Phone.....	79
Figure 5-24: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity – PDA	79
Figure 5-25: MCDA Level-2 (Cost – Initial Cost and Usage Cost) – Laptop	79
Figure 5-26: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity – Cell Phone.....	82
Figure 5-27: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity – PDA.....	82
Figure 5-28: MCDA Level-2 (Cost – Initial Cost and Connection Cost) – Laptop ...	82
Figure 5-29: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity – Cell Phone.....	85
Figure 5-30: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity – PDA.....	85
Figure 5-31: MCDA Level-2 (Cost – Connection Cost and Usage Cost) – Laptop ...	85
Figure 5-32: Weight effect individual criteria via minimum, average and maximum values (final score) for the Cell.....	86



Figure 5-33: Weight effect individual criteria via minimum, average and maximum values (final score) for the PDA	87
Figure 5-34: Weight effect individual criteria via minimum, average and maximum values (final score) for the Laptop	88
Figure 5-35: Average scores of the different field units when changing individual weights	89
Figure 5-36: Change in final score for changes of weights of individual criteria	90
Figure 5-37: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the Cell	92
Figure 5-38: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the PDA	93
Figure 5-39: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the Laptop	94
Figure 5-40: Average scores of the different field units when changing individual weights	96
Figure 5-41: Change in "one level up" scores for changes of weights of individual criteria	97



LIST OF TABLES

Table 2-1 GPRS Coding schemes.....	14
Table 3-1: Scoring “Non-Price” Criteria	28
Table 3-2: Scoring Price	28
Table 3-3 Total Scores	29
Table 4-1: MCDA steps 4, 5 - Process Capability.....	36
Table 4-2: Example for determining boundaries	37
Table: 4-3 Example boundaries	38
Table 5-1: UCN (Usability) Sensitivity	56
Table 5-2: UCN (Usability) Sensitivity 2	57
Table 5-3: MCDA Level-1 (Specification and Cost) Sensitivity.....	59
Table 5-4: MCDA Level-1 (Specification and Usability) Sensitivity	62
Table 5-5: MCDA Level-1 (Cost and Usability) Sensitivity	65
Table 5-6: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity	68
Table 5-7: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity	72
Table 5-8: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity	75
Table 5-9: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity	78
Table 5-10: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity...	81
Table 5-11: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity..	84



CHAPTER ONE

1 Introduction

In this chapter the basic background (conversion from the old WebForce dispatch system to the new WebForce dispatch system) that led to the identification, objectives and methodology of the project will be discussed. Clarification on the benefits and the value of the study will be made. A brief review of previous related projects will be discussed in which some proven methods/techniques were found. Some of these methods/techniques will be used in the process creation of an evaluation method that is intended for the functionality evaluation for GPRS (General Packet Radio Service) capable field units.



1.1 WebForce Background: Proposed System Upgrade

Telkom is currently using WebForce, a web-based database containing all fault information that occurs on the network. The WebForce is used to supply the field technicians (workforce) with their daily tasks. Each time a technician wants to receive a new task description or report on a task completion, he/she must make a dialup connection via GSM data call to the server. Telkom is proposing/planning to replace the existing system (as described above) with a system that will make use of the GPRS service supplied by GSM (Global System for Mobile communications) providers [1].

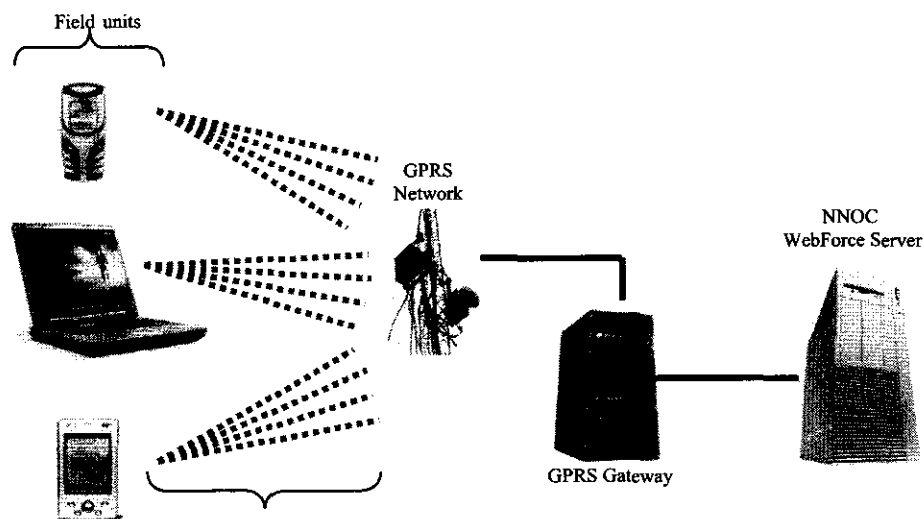


Figure 1-1: New WebForce Access Technology

The existing WebForce Server will stay in place, where in the new proposed system, as shown in Figure 1-1, remote access of the data will be achieved via GPRS. This will be done with a field unit (Personal Digital Assistant, GSM phone or Husky) which has GPRS capability. The field unit will communicate via the GPRS network and gateway with the GPRS/Server Interface, where the GPRS/Server Interface will connect to the WebForce Server at the NNOC (National Network Operating Centre), which will handle the distribution of tasks.

After a GPRS connection has been established once a day, the technician has to log onto the WebForce website to receive the tasks that have been assigned to him/her. After attending to the tasks assigned to him, he/she has to log the fault report to WebForce. Telkom has approximately 13000 telephone technicians, whose daily duties are mainly to fix line and networking faults [1].

With the GPRS logging method in place the tasks will be distributed more efficiently to the technicians in the field. This will enable the field technician to connect to the WebForce Server at any time and any place where GPRS coverage is available. GPRS is used because of its permanent connection and charging is only done on the volume of data that is transmitted and received [1].

1.2 Problem Statement

With the implementation of the new WebForce system Telkom will need to supply its workforce with field units that are capable of connecting to the WebForce server via GPRS connection. The field unit must also meet the minimum functionality requirements to enable the units to utilise the GPRS connection to its full potential. The utilisation of the GPRS connection does not only depend on the hardware but also the software that interacts with the hardware. Therefore, one has to see the field unit as a system that consists of hardware (PDA, GSM/GPRS phone or husky and the CF/PCMCIA card if required) and software (operating system, applications that are required for GPRS connection and the applications that are required to handle the information sent or received).

The focus of this project is the creation of a process that is used to evaluate methods in the evaluation of complete systems, evaluating from a higher point of view. The implementation of this evaluation process is focused specifically on the functionality evaluation of the field units that can be used in a WebForce dispatching system of Telkom.



1.3 Research Approach

The following will be the main steps of the research:

- A survey on GPRS, how it works and the performance requirements will be covered.
- A survey will be done on the techniques (QWS & NWS) and methods used that will lead to a comparative recommendation on which unit will be suitable for the field force automation system.
- A survey will be done on the requirements of the field units (the complete system, hardware and software) for the new field force automation system.
- The scoring weights for the criteria of the field units in the evaluation process will be determined.
- Three classes of units will be selected on which an evaluation will be performed.
- Sensitivity analyses on the evaluation process will be conducted.
- A recommendation will be made on which class of unit will be the best for the Telkom Workforce Automation case study.

1.4 Research Methodology

In the following section a short discussion of the focus areas of the research can be found, as well as a discussion of each phase and how each phase of the research will be conducted. Chapter 2 and 3 of this research report is devoted to a full literature study and the topic mentioned in the following section is only an introduction. In Figure 1-2 one can find the logical flow of the project.



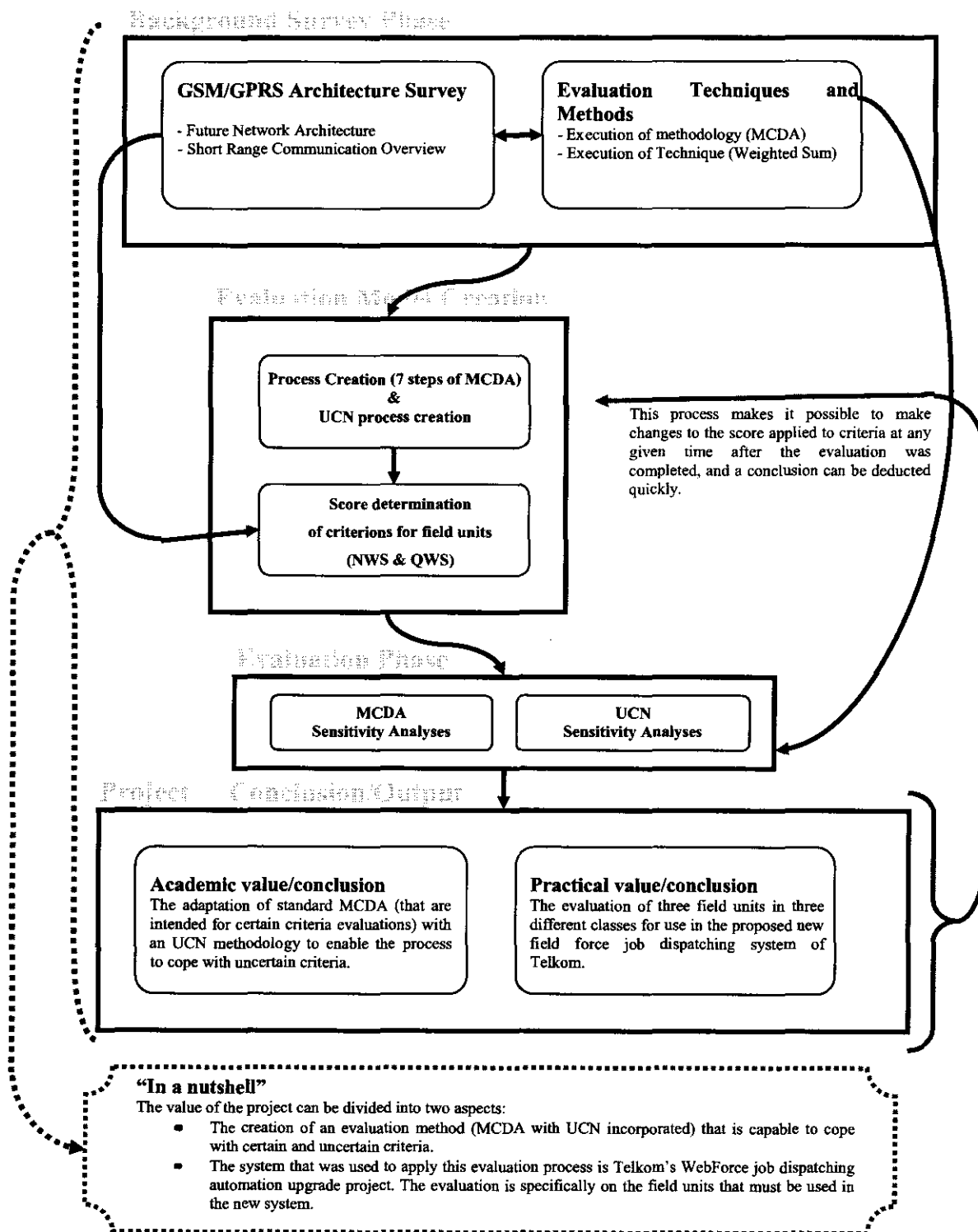


Figure 1-2: Phases of Evaluation Process



1.4.1 Background Survey Phase: What is GPRS

The first phase of the “*Background Survey Phase*” in the research will entail the following: What is GPRS? This will consist of the architecture of the GSM network and the expansions which will be required for implementing the GSM/GPRS network [2] (The basic network and mobile station operation is covered. The different security aspects that are included in the GPRS protocol/network will also be reviewed.

1.4.2 Background Survey Phase: Evaluation techniques and methods

The second phase of the “*Background Survey Phase*” in this research will entail the following: What is evaluation? How is it done (method)? With what is it done (technique)? During this phase of the research the focus will be on the evaluation process.

- **Method:** After a short literature survey, it seems that the most appropriate method and the one which will be used in this research will be criteria driven evaluation. This method is more or less abstract, criteria are defined and refined. The evaluation in these models aims at a measurement of the criteria.

To be more precise, a Multiple-Criteria Decision Aid (MCDA) will be used for the evaluation. This methodology is applied in the evaluation problems where the final decision depends on many, often contradictory, certain criteria (a criterion which has a certain value for all actions). This type of criteria makes use of classical evaluation techniques [4].

- **Technique:** Evaluation techniques are activities of evaluators which can be precisely defined in behavioural and organisational terms. It is important not to confuse “Evaluation techniques” with “Evaluation methods”, which usually constitute a combination of evaluation techniques (techniques are a subset of a method).

The techniques implemented in MCDA for the research project are Numerical Weight and Sum (NWS) and Qualitative Weight and Sum (QWS), or similar techniques and all of these techniques fall under the Weighted Sum (WS) [5] category.



1.4.3 Evaluation Model Creation: MCDA and UCN

The first phase of the "*Evaluation Model Creation*" in this research will focus on the physical implementation of the MCDA evaluation model, identifying and addressing its shortcomings. The implementation of the evaluation process will be done using the "Microsoft® Office Excel 2003" software package.

This implementation will include the implementation of a standard MCDA (that will handle the certain criteria) model with the addition of the UCN model (that will handle the uncertain criteria and the shortcoming of the MCDA model).

The seven basic steps of the MCDA process are:

- Define a set of Alternatives under evaluation in the model;
- Define the Type of the evaluation;
- Define the tree of the evaluation attributes;
- Define the set of associated Measures;
- Define the set of scales associated to the attributes (E);
- Define the set of criteria constructed in order to represent the user preferences (G);
- Define the preference aggregation procedure.

1.4.4 Evaluation Model Creation: Criterion scoring criteria

After the criteria are identified/selected, a survey has to be done to enable one to assign the correct scoring criteria for each criterion. This will be done by finding the norm scoring level for each criterion. The scoring criteria are created from density distribution figures that are to be constructed from data collected from a wide range of field units, the units ranging from cell phones and PDA's to laptops.



1.4.5 Evaluation Phase: MCDA and UCN Sensitivity analyses

In this section of the “*Evaluation Phase*” the sensitivity of the evaluation module will be reviewed. The interaction of all the criteria will be tested at all the levels of criteria. Two types of tests will mainly be conducted:

- A section where the weights of a specific level of criteria will be changed to see what the effect of this will be on the final score of the evaluation model.
- A section where the weights of a specific level of criteria will be changed to see what effect this will have on the “one level up” score of the evaluation model.

The analysis will be done by increasing the weights of the criteria in question from “0” (minimum) to “1” (maximum) and observing what effect it will make on the score in question. These tests will be conducted on both the MCDA and the UCN models.

1.4.6 Conclusion/Output

In this final phase of the project the results of the previous phases will be reflected on. This section will have two focus areas in which conclusions and recommendations will be made. The two focus areas are:

- Practical: Which class of field unit that was evaluated will be best suited for the requirements of the Telkom case study?
- Academically: The conclusion that can be drawn from the adaptation of standard MCDA (that are intended for certain criteria evaluations) with an UCN methodology to enable the process to cope with uncertain criteria and the application of methods/techniques where used that were actually intended for a smaller class of evaluation (this part of the conclusion goes more into the social computer science aspects).



1.5 Motivation

The demand for reliable telecommunication services is increasing continuously, thus forcing Telkom to improve the quality of the services that it is providing. This can only be done by making sure that Telkom's field force is working effectively and whose task it is to repair all the breakdowns on the network. Thus if the field technicians equipment is more suited to its purpose, the field force can be more effective.

As defined by Friedman and Wyatt [6]:" ... *evaluation is an empirical process. Data of varying shapes and sizes are always collected. It is also important to view evaluation as a service activity. Evaluation is tied to and shaped by the resource under study. Evaluation is useful to the degree that it sheds light on issues such as the need for, functioning, and utility of the information resource under study*".

It is important that the correct recommendation must be made due to the cost implications associated with a wrong decision. These implications can be in the form of saving money by buying a class of field unit that best suits its purpose, or by making the field force more effective.

1.6 Past/Related Studies

A few of the past/related studies are:

- **An Examination of Four User-based Software Evaluation Methods [7]:** Four methods; logged data, questionnaires, interviews and verbal protocol analyses have been the prominent base evaluation methods used, sometimes being combined in an attempt to provide a comprehensive evaluation.
- **Evaluation of Software Systems [8]:** lays out the different types of evaluation methods and techniques and gives the reason why evaluation is important.
- **Experiences with Usability Evaluation Methods [9]:** presents methods for usability evaluation and experiences in applying the methods. The work aims to



give background knowledge for selecting evaluation methods in various situations.

- **Knowledge based evaluation of software systems: a case study [4]:** This article identifies some common flaws in decision support for software evaluations. The discussion is an integrated solution through which significant improvements may be achieved, based on the Multiple Criteria Decision Aid methodology and the exploitation of packaged software evaluation expertise in the form of an intelligent system.
- **Methods and Practice of Software Evaluation: The Case of the European Academic Software Award [5]:** The article discusses theoretical and methodological problems of software evaluation in higher education. It criticizes the commonly used approach in product evaluation using numerically weighted lists of criteria.
- **An Experimental Comparison of Two Popular PDA User Interfaces [10]:** In this article we compare the usability of the user interfaces of the two most widely used operating systems for personal digital assistants are compared: Microsoft Pocket PC and Palm Computing PalmOS are compared.

1.7 Beneficiaries of this Research

The research of this project is aimed at 3 different beneficiaries of which the interests differ, Telkom – practical application, North-West University (Potchefstroom Campus) – academically and Student – complying with requirements for Master Degree.

- **Telkom South Africa**

An evaluation model is produced for the use of the evaluation of the field units for the new proposed “*Field force Automation*” project. Methods and techniques are presented that will make the evaluation process for future work easier. This process will enable one to make a recommendation to Telkom on the class of field unit that will best suit the task description.



- **North-West University (Potchefstroom Campus)**

A complete report on the evaluation process will serve as a reference for future research at the institution. The research can serve as a basis for a new research area for future work.

- **Student**

A background and knowledge of GPRS networks/field units and evaluation procedures will be gained during the implementation/creation of the evaluation process. A Masters Degree in Computer/Electronic Engineering will be achieved.

1.8 Conclusion

In this chapter the focus is on the basic background (conversion from the old WebForce dispatch system to the new WebForce dispatch system) that leads to the identification, the objectives and methodology of the project. The benefits and the value of the study are clarified. A brief review is also made of previous related projects; some of the proven methods that were used in these studies will be used in the system evaluation for GPRS capable field units.



CHAPTER TWO

2 GPRS Literature Survey

In this chapter a literature survey will be conducted that will cover all the aspects which will be needed to complete and understand the criteria of the evaluation process. This survey will also cover aspects of the GPRS system. The topics will cover GPRS architecture, security and compression. These aspects will be covered to enable one to apply the evaluation methods and techniques discussed in Chapter 3 that are to be used to evaluate the three different field unit classes.



2.1 GSM/GPRS Architecture Survey

2.1.1 Introduction

Communications are grounded on two essential well developed technologies: wireless communication and packet switching data networks. GSM (Global System for Mobile communications) is a widely adopted cellular network in more than 100 countries around the world. The great need and interest to add the capacity of data transmission to existing GSM networks leads to GPRS (General packet radio service). However, the existing GSM network is designed to provide voice services which cause the limitation in both maximum bit rate provided and the efficiency when handling data instead of voice.

The general trend in data applications is the generation of increasingly bursty data streams, which lead to an ever increasing demand for higher bandwidth. Although HSCSD (High-Speed Circuit-Switched Data) are delivering the bandwidth by combining multiple channels, it wastes valuable radio resources due to its circuit switched nature.

It has, therefore, been necessary to introduce packet switching in the existing GSM networks in order to provide an attractive bearer service for users wanting fast, efficient and cheap access to the Internet and/or their corporate intranet [11][12][13].

2.1.2 The GPRS terminals

GPRS and GSM systems provide inter-working and sharing of resources dynamically between users. For this reason, three types of terminals have been defined:

- **class-A MS** (Mobile Station) can carry a circuit switched and a packet switched connection simultaneously, enabling the subscriber to initiate or receive a voice call without interrupting a data transmission or reception activity.



- **class-B** MS is able to connect to both GSM and GPRS at the same time but an incoming voice call requires GPRS data transactions in progress to be suspended for the duration of the call. GPRS data transactions can then be resumed at the end of the voice call.
- **class-C** MS allows subscribers to access one service type only at a given time in an exclusive manner.

2.1.3 GPRS Coding Schemes

Depending on the environmental radio conditions, one of the four coding schemes (CS1, CS2, CS3 and CS4) can be selected. CS1 and CS2 offer good error detection and correction with low throughput; in the first step of the GPRS Protocol Stack only these two techniques may be used. CS3 and CS4 provide higher throughputs but have little or no error correction capabilities. Table 2-1 shows the different data rates that can be achieved with the different coding techniques [14].

Table 2-1 GPRS Coding schemes

User Data Rate	CS1	CS2	CS3	CS4
1 Timeslot	9.05 kbps	13.4 kbps	15.6 kbps	21.4 kbps
8 Timeslot	72.4 kbps	107.2 kbps	124.8 kbps	171.2 kbps

2.1.4 Limitations of GPRS

It should already be clear that GPRS is an important new enabling mobile data service which offers a major improvement in spectrum efficiency, capability and functionality compared with today's no voice mobile services. It is important to note that there are shortcomings with GPRS, which can be summarized as follow [11]:

- **Limited Cell Capacity for All Users:** GPRS does impact a network's existing cell capacity. Therefore, there are only limited radio resources that can be



deployed for different uses - use for one purpose precludes simultaneous use for another.

- **Speeds Much Lower in Reality:** Achieving the theoretical maximum GPRS data transmission speed of 172.2 kbps would require a single user taking over all eight timeslots without any error protection. Clearly it is unlikely that a network operator will allow all timeslots to be used by a single GPRS user.
- **Transit Delays:** GPRS packets are sent in all different directions to reach the same destination. This opens up the potential for one or some of those packets to be lost or corrupted during the data transmission over the radio link. The GPRS standards recognise this inherent feature of wireless packet technologies and incorporate data integrity and retransmission strategies. However, the result is that potential transit delays can occur.
- **No Store and Forward:** Store and Forward Engine in the SMS (Short Message Service) is the heart of the SMS Centre and key feature of the SMS service, but there is no storage mechanism incorporated into the GPRS standard (up to date), apart from the incorporation of interconnection links between SMS and GPRS.

2.1.5 Conclusion of GPRS Architecture Survey

In the above section the architecture of the GPRS network is summarised. In this section a few aspects came to light that have to be taken into account when evaluating the field units of this case study. These are the four coding schemes (CS1, CS2, CS3 and CS4) and the number of time slots that will be available for each field unit (and the number of time slots that each field unit is able to utilise) which need to be taken into account. It is also evident that the storage capability of the field units will need to be considered.



2.2 Future Network Architecture

2.2.1 Introduction

The second generation of mobile telephony has in recent years made mobile communication an everyday occurrence all over the world. In South Africa, Europe, Asia and South America the leading technology for this is GSM. GSM is a digital circuit switched telephony network with many features such as SMS and GPRS Application included in the standards.

2.2.2 GSM, GPRS, EDGE and UMTS

While excellent for voice services, **GSM** is not ideally suited for data traffic. The reason for this is that GSM is circuit switched, which means that it takes some time to set up a connection. Normally this time is somewhere between 10 and 45 seconds. Since most mobile data services tend to be used during a short time, a large part of the time it takes to use a service is spent waiting for the connection to be set up.

GPRS provides a solution to the problem of long connection set-up times. This is done by introducing new nodes into the GSM network to allow packet switched data traffic. Voice services still use circuit switched connections. With GPRS, any channel not busy with a call is pooled into one packet channel that is shared among all users that want to send and receive data. When more users make calls in the cell, the available bandwidth for data traffic decreases and when they hang up, it increases. The bandwidth in GPRS is about 20-30% faster than GSM on average, but it is highly variable depending on the circumstances.

EDGE works with the same principles as GPRS, but can use a more flexible error correction scheme over-the-air. This leads to higher average bandwidth, but with more variations.

The evolution from GSM over GPRS to EDGE can be done in the same system infrastructure. Upgrades to hard- and software are necessary, but the overall system



architecture remains. When moving to UMTS (Universal Mobile Telecommunications Systems) all this changes. The frequency is changed from 900/1800 MHz to 2 GHz. The schemes for multiple access are changed from TDMA (Time Division Multiple Access) to WCDMA (Wideband CDMA). Most importantly, the basic transport mode is packet switching instead of circuit switching. Instead of providing data traffic over voice channels, UMTS provides voice services over a packet data network.

Bandwidth in UMTS will be very different in different places, the maximum bandwidth of 2 Mbps will be available in certain small areas if a user is standing still and using the base station alone. A user driving a car in rural areas will probably not be able to use more than about 100 kbps [15].

2.2.3 Conclusion of future Network Architecture

In the section above a short survey on wireless architecture update capabilities was given. This was done to enable one to take into account the chance of network architecture upgradeability. This is important in the evaluation process (to take into account that the network architecture can be upgraded and that the field units must also be upgradeable or replaceable).

2.3 Short Range Communication Overview

2.3.1 Introduction

The main purpose of this section is to review short range communication capabilities of field units. This type of communication could be used when a field unit moves into an enclosed environment, in the case of Telkom this could be an exchange. Under normal conditions the unit will make use of an GPRS connection to the Telkom WebForce and the moment when the unit moves into an indoor facility the communication can switch over to Wi-Fi or Bluetooth which is connected to a fixed Telkom line (this can be done to reduce the cost of data sent, because data over a landline is cheaper).



2.3.2 Bluetooth

Bluetooth is a “short wire” replacement for the mass of cables used to connect “field unit” devices to share information. When referring to “field unit” devices they include portable PCs, mobile telephones, PDA's, etc. As Bluetooth develops, more enabled devices will be found, particularly around the work place. Bluetooth is designed primarily to work in the background and because the speeds are much lower than Wi-Fi, it should be considered as a low-key automated way of exchanging and synchronizing localised information. However, Bluetooth does have networking capabilities to a maximum of seven users, with one machine as the master. The maximum working reach for Bluetooth is 100 m but will initially be around 10m.

The nominal distance for a Bluetooth device with a 1mW RF power output is 10 metres and this is extendable to 100 metres by increasing the power to 100 mW. The raw data rate for a Bluetooth device is 1Mbps. However, the available data rate is 723 kbps. This data rate is sufficient for both voice and data communication making Bluetooth hardware integration an increasingly viable option in many applications [16].

2.3.3 Wi-Fi

Wi-Fi is the “long wire” (network cable from desk to hub/server) wireless replacement technology based on the 802.11 standard. It is designed to allow users to log onto an office/business network without the need to attach physically via a network card. As long as the user has network access rights, he/she should be able to log onto the network from anywhere within the network area (building or site). It simplifies the network infrastructure as physical cabling is only needed to connect the wireless access point to a hub or server. By removing physical cabling costs can be saved and there is less physical structure to fail/troubleshoot. It also increases the flexibility of the workforce in being able to go anywhere within the network but remain connected.

- The 802.11b standard offers speeds with a theoretically maximum rate of 11M bps in the 2.4 GHz spectrum band.



- The 802.11a standard offers speeds with a theoretically maximum rate of 54M bps in the 5 GHz band. The 802.11a hardware is just beginning to be introduced.
- The 802.11g is a new standard for data rates of up to a theoretical maximum of 54M bps at 2.4 GHz [17].

As with other wireless technologies, one will not obtain the theoretically maximum speeds. The Wi-Fi wireless data industry is notorious for hyping the theoretical data rates, rather than the typical data speeds.

2.3.4 Conclusion of Short Rang Communication

During this section a brief overview of short range communication capabilities of field units was made. This type of communication could be used when a field unit moves in an enclosed environment. Under normal conditions the unit will make use of a GPRS connection to the Telkom WebForce. The moment the unit moves into an indoor facility, the communication can switch over to Wi-Fi or Bluetooth which is connected to a fixed Telkom line. Both these communication methods will be able to be applied to the field units for indoor use and, therefore, the determining factor for which one to use will be determined during the evaluation phase.

2.4 Conclusion

In this chapter the focus was placed on the more advanced concepts of this dissertation. A more comprehensive discussion of these topics discussed in Chapter 1 was given. The survey covered aspects of the GPRS system. The topics covered GPRS architecture to enable one to understand GPRS data transfer and all the aspects involved in the transportation of data and the security surrounding this transportation.

In the following section an in-depth view of the evaluation method/techniques to be used for the evaluation of the field units will be given.



CHAPTER THREE

3 Evaluation Literature Survey

In Chapter 3 a literature survey which covers all aspects of the MCDA evaluation method that are needed to understand the evaluation process will be presented. This survey will also cover aspects of evaluation methods and techniques. The aspects that are being covered in this chapter will enable one to apply the evaluation methods and techniques to this case study.



3.1 Evaluation Techniques and Methods

Criteria driven evaluation methods have proved to be extremely helpful techniques for making decisions from criteria that have certain values (in a defined numerical range). This type of evaluation can be used in a wide range of decisions. In most of these applications the interest is in only one attribute of a system. This poses to be a problem because in a large range of problems one needs to make decisions based on multiple criteria. This is where the MCDA makes its appearance. This evaluation method makes its evaluation based on more than one attribute (multiple criteria).

This methodology is applied in the evaluation problems where the final decision depends on many, often contradictory, criteria. This type of criteria makes use of classical evaluation techniques such as linear programming and analytical hierarchy process.

3.1.1 Method (MCDA)

Criteria driven evaluation models start with assumptions about the structure of the design process in which criteria are defined and give advice to derive measurables from the criteria. Because these models focus on criteria and measurables, there is no close connection to a design model. This type of model is aimed at a product evaluation from a quality point of view. It defines a specific process model and some general quality characteristics (e.g. functionality, reliability and usability).

Although it is useful to express a decision problem in a kind of summary phrase, a decision problem is only truly well-defined once are identifies the following, using the standard terminology of MCDA:

- The set of possible (mutually exclusive) action one can take (these are the alternatives).
- A set of criteria, which are functions defined in actions.
- A set of constraints which are the properties of the criteria (these can also be thought of as preferences).



3.1.2 Techniques

Evaluation techniques are activities of evaluators which can be precisely defined in behavioural and organisational terms. It is important not to confuse "evaluation techniques" with "evaluation methods", which usually constitute a combination of evaluation techniques (techniques are a subset of a method).

After reviewing the relative literature [20][21][22], it seems that the most commonly used techniques used in MCDA are Numerical Weight and Sum (NWS) and Qualitative Weight and Sum (QWS), or similar Weighted Sum (WS) techniques.

- **NWS:** The relevance (weight) of each criterion is set using a scale from e.g. 1-3, 1-5 or 1-10. The evaluand is rated for each criterion. Rating multiplied by the weight gives the result for each criterion, results are added up for each evaluand. The final result is a single number for each evaluand. The evaluands (the units to be evaluated) can be ordered by this number (ranking), the one with the highest score being the "winner" [4].
- **QWS:** As in the NWS method a list of criteria is established and weighted. The crucial difference is that QWS is not based on the assumption of an interval or ratio scale. After the criteria the weights of the criterion have to be determined and the weight determines the range of values that can be used to measure an evaluand's performance [4].

3.2 Execution of methodology (MCDA) [19]

In the following section a brief layout of the method (MCDA) to be used can be found. The main steps to be followed are: the set of alternatives under evaluation in the model, the type of the evaluation, the tree of the evaluation attributes, the set of associated measures, the set of scales associated to the attributes, the set of criteria constructed in order to represent the user's preferences and the preference aggregation procedure.



An evaluation problem solved by MCDA can be modelled as a septuplet $\{A, T, D, M, E, G, R\}$ where:

- A is the set of alternatives under evaluation in the model.
- T is the type of the evaluation.
- D is the tree of the evaluation attributes.
- M is the set of associated measures.
- E is the set of scales associated to the attributes.
- G is the set of criteria constructed in order to represent the user's preferences.
- R is the preference aggregation procedure.

3.2.1 Step 1: Definition of the evaluation set A .

The first step is to define the set of possible choices exactly. Usually there is a set A of alternatives to be evaluated and the best must be selected. The definition of A could be thought of as first-level evaluation, because if some alternatives do not meet certain requirements, they may be rejected from this set.

3.2.2 Step 2: Definition of the type T of the evaluation.

In this step one must define the type of result required. Some possible choices are the following:

- **Choice** — partition the set of possible choices into a subset of best choices and a sub-set of not best ones;
- **Classification** — partition the set of possible choices into a number of sub sets, each one having a characterization such as good, bad, etc.;
- **Sorting** — rank the set of possible choices from the best choice to the worst one;
- **Descriptions** — provide a formal description of each choice, without any ranking.



3.2.3 Step 3: Definition of the tree of evaluation attributes D.

In this step the attributes which will be taken into account during the evaluation and their hierarchy must be defined. Attributes that can be decomposed in sub-attributes are called compound attributes. Sub-attributes can also consist of sub-sub-attributes etc. The attributes that cannot be divided further are called basic *attributes*.

3.2.4 Step 4: Definition of the set of measurement methods M.

For every basic attribute d one must define a method Md that will be used to assign values to it. There are two kinds of values, the arithmetic values (ratio, interval or absolute) and the *nominal values*. The first type of values are numbers, while the second type are verbal characterizations, such as “good”, “bad”, “big”, “small”, etc.

A problem with the definition of Md is that d may not be measurable because of its measurement being non-practical or impossible. In such cases an arbitrary value may be given, based upon expert judgement, introducing a subjectivity factor. Alternatively, d may be decomposed into a set of sub-attributes $d1, d2, \dots, dn$, which are measurable. In this case the expression of arbitrary judgement is avoided, but subjectivity is involved in the decomposition.

3.2.5 Step 5: Definition of the set of measurement scales E.

A scale Ed must be associated to every basic attribute d . For arithmetic attributes, the scale usually corresponds with the scale of the metric used, while for nominal attributes, Ed must be declared by the evaluator. Scales must be at least ordinal, implying that, within Ed , it must be clear which of any two values is the most preferred.

3.2.6 Step 6: Definition of the set of Preference Structure Rules G.

For each attribute and for the measures attached to it, a rule or a set of rules have to be defined, with the ability to transform measures to preference structures. A preference structure compares two distinct alternatives on the basis of a specific attribute. Basic



preferences can be combined using some aggregation method to produce a global preference structure.

For example, let $a1$ and $a2$ be two alternatives and let d be a basic attribute. Also let $md(a1)$ be the value of $a1$ concerning d and let $md(a2)$ be the value of $a2$ concerning d . Suppose that d is measurable and of positive integer type. In such a case, a preference structure rule could be the following:

- product $a1$ is better than $a2$ on the basis of d , if $md(a1)$ is greater than $md(a2)$ plus K , where K is a positive integer;
- products $a1$ and $a2$ are equal on the basis of d , if the absolute difference between $md(a1)$ and $md(a2)$ is equal or less than K , where K is a positive integer.

3.2.7 Step 7: Selection of the appropriate aggregation method R.

An aggregation method (R) is an algorithm, capable of transforming the set of preference relations into a prescription for the evaluator. A prescription is usually an order on A . The selection of an aggregation method depends on the following parameters:

- the type of the problem;
- the type of the set of possible choices (continuous or discrete);
- the type of measurement scales;
- the kind of importance parameters (weights) associated to the attributes.

3.2.8 Conclusion of Evaluation Method (MCDA)

In the above section the MCDA method was discussed and in this section it was evident that there are limitations to this method. The limitations need to be overcome to enable the MCDA method to be applied to decision making problems where the criteria are uncertain (the criteria does not have a specific value). The three assumptions that MCDA make are:



- That the criteria are well defined (hence for a given action a it is obvious how to compute $g(a)$ for a given criteria g).
- The relevant criteria are certain (and hence for a given action a and criteria g the value $g(a)$ is deterministic rather than stochastic).
- That the relevant criteria are independent of each other.

	Functionality evaluation of field units
Objective	To get the unit that is optimized to be a field unit for a dispatching system and the environment in which it works
Perspective	Decision maker: Corporation management Key stakeholders: Field force technicians that have to use the field unit
Decision problem	To be determine the field unit that offers the optimal usability in the work place of the dispatching system technicians
The set of possible actions	Rank the field unit (cell phone, PDA and laptop) from the most suitable unit to the less suitable unit according to its usability in its workplace
Criteria (as define by actions)	File read time: This is the time it takes to access a file on unit, plus the time it takes for the unit operator to read the file File write time: This is the time it takes to access a file editor on the unit, plus the time it takes to actually write the document/ task report
Constraints (properties of criteria that one specifies as define)	File read time: > 100 word/minute File write time: > 15 word/minute
External factors (variables one cannot control, but which can influence the value of criteria for a given action)	Field unit location (office, in vehicle, on site)
Internal factor (variables one can control, but which can influence the value of criteria for a given action)	User capability (low, medium and high with respect to metric level)

Figure 3-1: Key MCDA concepts summarized



These can be seen as the limitations of MCDA because they restrict the evaluation methods to problems that only consist of certain criteria. In the UCN section a discussion of how the problem can be fixed and the limitations overcome with UCN's will be given.

3.3 Execution of Technique (Weighted Sum)

In the following section how to apply Weighted Sum (WS) techniques to priced and non-priced criteria in an evaluation process will be discussed.

If the evaluation is highly technical or difficult, emphasis should be placed on the weightings of the total of the non-price criteria and the sub-attributes of technical skills and methodology. If the evaluation aims at cutting costs, emphasis should be placed on the weightings of the total of the price criteria and the sub-attributes.

3.3.1 Scoring "Non-Price" Criteria [3]

The assessment procedures are as follows:

- Add the individual scores for each non-price criterion. Each criterion is given a point score from 0 (poor) to 10 (excellent) in increments of 0.5.
- Weigh the individual scores for each non-price criteria according to the pre-determined weightings. The weighted score is calculated by multiplying the score by the weight. In the example given in Table 3-1, the weighted score for tender 1, criteria 1 is calculated as $9 \times 20\% = 1.80$.
- The sum of non-price scores for each tender is then normalized to 10. Normalizing is a transformation applied uniformly to each element in a set of data so that the set has some statistical property.
- The following formula is applied to normalize the non-price scores:

$$= \frac{\text{Sum of non - price score for each tender} \times 10}{\text{Highest sum of non - price scores}}$$

- This score is then adjusted for the total weighting of all the non-price criteria to obtain the overall weighted non-price score.



The example below shows how the weighted score is calculated and to normalize non-price scores:

Table 3-1: Scoring "Non-Price" Criteria

		Tender 1	Tender 2	Tender 3
Criteria 1, weight 20%	Score	9	9	8
	Weighted score	1.8	1.8	1.6
Criteria 2, weight 10%	Score	7.5	7	8
	Weighted score	0.75	0.7	0.8
Criteria 3, weight 10%	Score	9	7	6
	Weighted score	0.9	0.7	0.6
Total weighted sum = 40%		3.45	3.2	3
Normalised non-price		10	$3.20 \times 10/3.45$	$3.00 \times 10/3.45$
		10	9.28	8.7
Weighted non-price	40%	4	3.712	3.48

The highest non-price total score is given as a score of 10 and the other sums are ranked accordingly in proportion.

3.3.2 Scoring Price[3]

Scores for price are based on the following method: (Note that the lower the price, the higher the score.)

$$\text{Normalised price score} = \frac{\text{lowest tender price} \times 10}{\text{tender price}}$$

Table 3-2: Scoring Price

Tenderer	Tenders (in ascending order)	Normalised Price
Tender 2	R1 282 000	10
Tender 3	R1 333 000	9.62
Tender 1	R1 925 000	6.66

3.3.3 Total Scores

The total scores for the examples given in Table 3-1 and Table 3-2 is given in Table 3-3.



Table 3-3 Total Scores

		Tender 1	Tender 2	Tender 3
Criteria 1, weight 20%	Score	9	9	8
	Weighted score	1.8	1.8	1.6
Criteria 2, weight 10%	Score	7.5	7	8
	Weighted score	0.75	0.7	0.8
Criteria 3, weight 10%	Score	9	7	6
Total weighted sum = 40%	Weighted score	0.9	0.7	0.6
Total non-price criteria		3.45	3.2	3
Normalised non-price		10	$3.20 \times 10/3.45$	$3.00 \times 10/3.45$
		10	9.28	8.7
Weighted non-price	40%	4	3.71	3.48
Normalised price		10	9.62	6.66
Weighted Price	60%	6	5.77	4
Totals	100%	9.71	9.25	8

3.3.4 Equivalency Rule

When the difference between the first and second ranked scores is less than 3% the lowest price tender of the two is taken as the preferred tender unless there are extraordinary reasons for not doing so. The "3% rule" is based on a statistical review of the variances in the subjectivity of the assessment panels' individual scoring [3].

3.3.5 Difference between QWS and NWS

- **NWS:** The relevance (weight) of each criterion is set using a scale from e.g. 1-3, 1-5 or 1-10. The evaluand is rated for each criterion. Rating multiplied by the weight gives the result for each criterion. The final result for the evaluand is the criteria added up to give a single number. The evaluands can be ordered by this number (ranking), the one with the highest score being the "winner" [5].
- **QWS:** As in the NWS method a list of criteria is established and weighted. The crucial difference is that QWS is not based on the assumption of an interval or ratio scale. After the criterion/boundaries of the weights of the criterias has been determined, the weight of a criterion determines the range of values that can be used to measure an evaluand's performance [5].



3.3.6 Conclusion of Evaluation Techniques

In the section above a brief discussion of the techniques (QWS and NWS) which are going to be used in the evaluation of the WebForce case study is given. To be able to cover a wider range of criteria, both of the techniques will be used during the evaluation process.

3.4 Conclusion

In this chapter the focus was on some advanced concepts of evaluation processes. A literature survey covering all the significant aspects needed to complete and understand the evaluation process was given. The survey covered evaluation methods (MCDA) and techniques (Weighted Sum) that are used in this case study to evaluate the 3 different field unit classes.

The MCDA method and techniques were discussed and it is evident that there are limitations to this method. The limitations need to be overcome to enable the MCDA method to be applied to decision making problems where the criteria are uncertain (the criteria does not have a specific value). In the following chapter, focus will be on the evaluation process creation using MCDA for the case study, as well as how the limitations of MCDA will be overcome with UCN's.



CHAPTER FOUR

4 Evaluation Process Creation

In the previous chapter we discussed the MCDA method was discussed, and it is evident that there are limitations to this method. The limitations need to be overcome to enable the MCDA method to be applied to decision making problems where the criteria are uncertain or the criteria do not have a measurable value. In the following section the MCDA evaluation method will be applied to the case study (Telkom WebForce system upgrade). A discussion of a method on how the problems posed by MCDA can be fixed and the limitations overcome by using UCN's is also presented.



4.1 Application of Standard MCDA Methodology to a Case Study [19]

System evaluation problems fall into the class of decision making problems that could be handled through the Multiple-Criteria Decision Aid (MCDA) methodology. The system used for this case study consists of a web-based database containing all fault information that occurs in a telecommunication network. The field force server is used to supply the field technicians (workforce) with their daily chores. The field units make use of the GPRS (General Packet Radio Service) service supplied by GSM providers to connect to the server (as shown in Figure 4-1). The functionality evaluation of the field units that have to be used in the above system will act as the case study for this chapter.

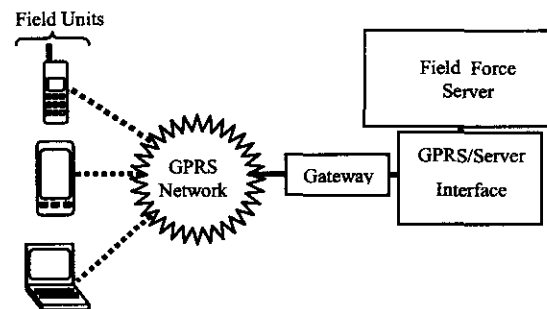


Figure 4-1: Field force dispatching system

The main steps to be followed are: the set of alternatives under evaluation in the model, the type of the evaluation, the tree of the evaluation attributes, the set of associated measures, the set of scales associated to the attributes, the set of criteria constructed in order to represent the user's preferences and the preference aggregation procedure.

4.1.1 Step 1: Definition of the evaluation set (A).

Step description: *The first step is to define the set of possible choices exactly. Usually there is a set A of alternatives to be evaluated and the best (rank of possible outcomes) must be selected.*

Application: To explain how one applies MCDA to a case study, it will be applied to the functionality evaluation of the field force dispatching system. The evaluation set of the case study will contain three types of field units.

$$A = \{\text{Cell Phone, PDA, Laptop}\}$$

4.1.2 Step 2: Definition of the type T of the evaluation.

Step description: *In this step the type of result required must be defined. Some possible choices are: Choice, Classification, Sorting and Descriptions*

Application: In this case study it was decided to use the ranking of the set (A) of possible choices from the best choice to the worst. This will enable one to identify the possible strong and weak points of each choice at completion of the evaluation. If one can identify the weaknesses/strengths in certain areas of each field unit, one would be able to apply each device to the right purpose.

$$T(A) = \text{Ranking}$$

4.1.3 Step 3: Definition of the tree of evaluation attributes

Step description: *In this step the attributes that will be taken into account during the evaluation and their hierarchy must be defined. Attributes that can be analyzed in sub-attributes are called compound attributes. Sub-attributes can also consist of sub-sub-*



attributes etc. The attributes that cannot be decomposed further are called basic attributes.

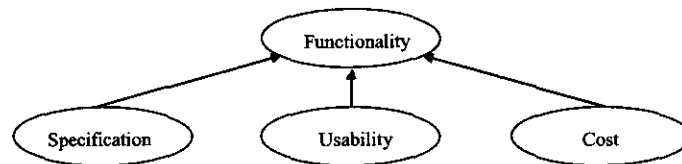


Figure 4-2: Evaluation tree of case study

Application: In Figure 4-2 a simplified view of the case study can be found. The functionality is divided into three main attributes (specification, usability, cost). Each one of these attributes has a compound nature and must be decomposed until all the attributes cannot be decomposed further.

An example of the decomposition can be seen below. In this example the specification criteria that is a compound criteria are decomposed down to it's basic criteria. A complete view of this decomposition can be found in Appendix A:

Specification (d1)

- Processing Capability (d11)
 - File type handling (d11.1)
 - File open time (d11.2)
 - File open time with less than 300 characters (text only) (d11.2.1)
 - File open time with more than 300 characters (text only) (d11.2.2)
 - File open time with more than 300 characters + picture (d11.2.3)
 - File close time (d11.3)
 - File close time with less than 300 characters (text only) (d11.2.1)

∴
∴
∴
∴

Usability (d3): UCN – one is unable to divide the usability into certain criteria (which is an assumption that MCDA makes).



4.1.4 Step 4: Definition of the set of measurement methods (M)/Step 5: Definition of the set of measurement scales (E).

In the following section only a summary of steps 4 and 5 is given. In Appendix C one can find the complete description of how the measurement scales are determined.

Step 4 description: *For every basic attribute d one must define a method M_d that will be used to assign values to it. There are two kinds of values, the arithmetic values (ratio, interval or absolute) and the nominal values. The first type of values are numbers, while the second type are verbal characterizations, such as "good", "bad", "big", "small", etc.*

Step 5 description: *A scale E_d must be associated to every basic attribute d . For arithmetic attributes, the scale usually corresponds to the scale of the metric used, while for nominal attributes, E_d must be declared by the evaluator. Scales must be at least ordinal, implying that, within E_d , it must be clear which of any two values is the most preferred*

Application: Viewing at the *Process Capability (d11)* which is a sub-attribute of the *Specification* attribute, the following can be defined:

This type of measurement classification must be done for all the sub-attributes, but there seems to be a problem in classifying the *usability* attribute. The sub-attributes of the attribute can be measured for certain actions only and no actions are uniform for all working conditions. This is where MCDA reaches its limits and one has to find a method to overcome this problem.

Note: Table 4-1 is only an example of how it should be done, a full version of the table can be found in Appendix C.



Table 4-1: MCDA steps 4, 5 - Process Capability

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d11					
d11.1	Md11.1	Nv	Ed11.1	Text only (characters < 300)	0.1
				Text only (characters ≥ 300)	0.2
				Text + picture (separate: text + jpeg, bmp)	0.3
				Text + picture (single file: .doc, .pdf)	0.4
d11.2					
d11.2.1	Md11.2.1	Av	Ed11.2.1	time ≤ 0.75 s	0.5
				0.8 s ≤ time ≤ 2 s	0.35

4.1.4.1 Example of determining criteria boundaries

The scoring criteria is created from a density distribution figure (e.g. Figure 4-3) that was calculated from data that was collected from a wide range of field units, the units ranging from cell phones and PDA's to laptops. This example is to illustrate how the criteria boundaries are determined; in appendix E a complete illustration of all the criteria can be found. On the density distribution figure one can see two lines, one of which is a normalized version of the other. The one with the biggest amplitude is the normalized one and this line is used in the selection of the scoring boundaries.

The criterion for scoring is selected according to the density plot in Figure 4-3.

- The highest score (0.5) is awarded if the unit performs better than the point in which the density plot reaches 100 %.
- The average score (0.35) is awarded to the unit if its performance falls between 100% and 60% in the density plot or the centre between 3 times the point at which the maximum point in the density plot was reached and the maximum point at which the density plot reaches 60% (if the boundary selected is smaller than the 60% point).
- The below average score (0.15) is awarded to the unit if its performance falls between 60% and 10% in the density plot or the centre between 3 times the point



that was selected in the previous upper boundary and the maximum point at which the density plot reaches 10% (if the boundary selected is smaller than the 10% point).

- The bad score (0) is awarded to the unit if its performance falls between 10% and 0% in the density plot.

The multiplication factor of “3” that was used in the above section can be derived from calculation of the probability density plot. In the calculation of the probability density plot an absolute range of values/boundaries was determined “intervals = (max-min)/20”. The deviation spread was selected to be over 3 intervals, thus allowing the selection of the multiplication factor up to 3.

Table 4-2: Example for determining boundaries

Open time	score
time $\leq$ boundary 1	0.5
boundary 1 $\leq$ time $\leq$ boundary 2	0.35
boundary 2 $\leq$ time $\leq$ boundary 3	0.15
boundary 3 $\leq$ time	0

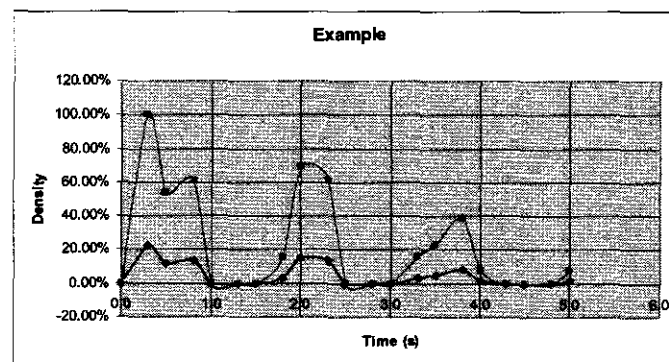


Figure 4-3: Example for determining boundaries

Boundary 1: time = 0.25 s at 100 %

Boundary 2: time = 2 s at 60%

$$3 * \text{boundary 1} = 0.75 \text{ s}$$



$$\begin{aligned}
 \text{Thus boundary 2} &= (3 * \text{boundary 1}) + [(\text{time at 60\%}) - (3 * \text{boundary 1})]/2 \\
 &= (0.75) + [(2 - 0.75)]/2 \\
 &= 1.375 \text{ s}
 \end{aligned}$$

Boundary 3: time = 4.0 s at 10%

$$3 * \text{boundary 2} = 4.125 \text{ s}$$

Because: time (10%) < 4.125

Thus boundary 3 = 4 s

Table: 4-3 Example boundaries

Open time	score
time $\leq$ 0.25 s	0.5
0.25 s $\leq$ time $\leq$ 1.375 s	0.35
1.375 s $\leq$ time $\leq$ 4 s	0.15
4 s $\leq$ time	0

4.1.5 Step 6: Definition of the set of Preference Structure Rules (G).

Step description: For each attribute and for the measures attached to it, a rule or a set of rules have to be defined, with the ability to transform measures to preference structures.

Application: For the evaluation process there are no additional “Structure Rules”. The reason is because sensitivity analyses on the evaluation process are going to be done and any biasing constants/variables in the equation are not wanted.

4.1.6 Step 7: Selection of the appropriate aggregation method R.

Step description: An aggregation method is an algorithm, capable of transforming the set of preference relations into a prescription for the evaluator. A prescription is usually an order on A.

Application: Two types of aggregation methods R that can be used in the case study are numerical weighted sum (NWS) and qualitative weighted sum (QWS). Both of these



methods are used. The QWS that were used in the criteria were the measurement values of a “nominal values” type, these nominal values were transformed into “arithmetic values” in the scoring section. This enables one to do/run the whole evaluation with a NWS technique. The aggregation algorithms are as follow:

Note: In the following section an example of how it should be done is given. A full version of the table can be found in Appendix D.

4.1.6.1 Level 3 Aggregation algorithms

Processing Capability [$R11(a,d11)/Md11(a,d11)$] :

$$R11(a,d11) = [Md11.1(a)*W(a,d11.1)] + [Md11.2(a)*W(a,d11.2)] + ... \\ ... + [Md11.12(a)*W(a,d11.12)] + [Md11.13(a)*W(a,d11.13)]$$

$$\text{Where: } R11.2(a,d11.2)/Md11(a,d11.2) = [Md11.2.1(a)*W(a,d11.2.1)] + ...$$

::
::
::
::

4.1.6.2 Level 1 Aggregation algorithm

Evaluation score [$R(a,d)/Md(a,d)$] :

$$R(a,d) = [Md1(a)*W(a,d1)] + [Md2(a)*W(a,d2)] + \\ [Md3(a)*W(a,d3)]$$

Where $Md3(a)$ is the scoring value that will be returned from the UCN evaluation model.

4.1.6.3 Summary

Now that all of the aggregation algorithms for the MCDA evaluation model have been determined, one can simply replace the variable a with the basic scores of the elements that are going to be evaluated:

a1: Cell phone

a2: PDA

a3: Laptop



After each of these variables have been inserted into the algorithms and the scores have been determined on all of the criteria levels, one can normalize the tree score in each experiment (no matter on what level you are currently working on). Now the field units can be ranked according to the numerical values on any criterion/level on the MCDA evaluation model.

4.2 Adapting the MCDA Method

In the previous section in the discussion of the MCDA it was evident that there are limitations to the method. These limitations need to be overcome to enable the MCDA method to be applied to decision making problems where the criteria are uncertain, or the criterion does not have a measurable value. In this section a discussion on how the problem can be fixed and the limitations overcome by using UCN's is given.

Criteria driven evaluation models start with basic assumptions about the structure of the design process in which criteria are defined. The three critical assumptions are [20]:

- That the criteria are well defined (hence for a given action a it is obvious how one can compute $g(a)$ for a given criteria g).
- The relevant criteria are certain (and hence for a given action a and criteria g the value $g(a)$ is deterministic rather than stochastic).
- That the relevant criteria are independent of each other.

These can be seen as the limitations of MCDA because they restrict the evaluation methods to problems that only consist of certain criteria. In real life decision making, the criteria used for the evaluation are not always certain [21].

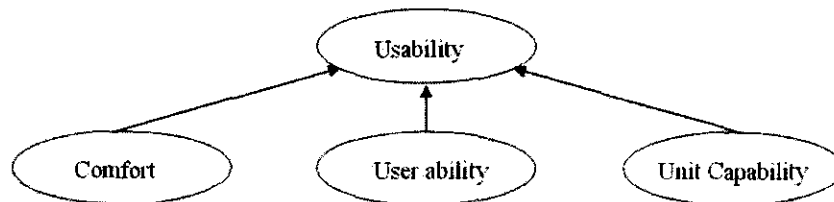


Figure 4-4: Definition of system usability



Uncertain Criteria Networks (UCN) is proposed as a method to overcome the problem of uncertain criteria problems in MCDA based evaluation in high level evaluation. UCNs can model problems which involve uncertainty. An UCN is a directed graph such as the one shown in Figure 4-4. The nodes of the UCN represent uncertain variables and the arcs (lines) are the links between the variables. Associated with each node is a set of conditional probability functions that are parents.

4.2.1 Defining Criteria for UCN's

The theory of MCDA assumes that criteria are always well defined. The case study confirms that this is not true for all real-life problems. Criteria that are not well defined can be defined as a "synthetic criterion". Synthetic criteria are often decomposed into lower level attributes that are assumed to be well defined [22]. In UCN are makes use of synthetic criteria to help handle uncertain criteria in MCDA.

Formally a criteria is a function from a set of actions in some ordered set. In this case study the *user file read time* and *user file write time* are the criteria (*comfort*, *user ability* and *unit capability* which are fuzzy criteria in MCDA are converted to *user file read time* and *user file write time* which are synthetic criteria that are used in the UCN). Therefore, a well defined criterion one first needs to define the order set (which is the range of the function and which may be also thought of as the measurement scale) to enable MCDA to incorporate the UCN.

Defining synthetic criteria is the same as defining measures for attributes. Often a simple ordinal scale may be sufficient for this purpose. A measure for an attribute should never be seen as defining an attribute. While it may be sufficient for this purpose to measure *usability* on a simple scale (good, medium, bad), this measurement does not replace all existing levels about *usability* and, therefore, does not re-define it. What one needs to be careful of is to distinguish between different types of "uncertainty" that arise in decision making problems.



- Uncertainty in meaning – where one has a “synthetic” criteria that is not properly define
- Imprecision – where the measurement process is inaccurate even though it may be well defined.

Application: In the case study, usability can be decomposed into comfort, user ability and unit capability. It is important to note that decomposition alone is not sufficient to define a high level criterion. Synthetic attributes are those whose definition are uncertain (vague or fuzzy). UCNs are used to handle these fuzzy criteria (*usability*).

For “*user file read time*” and “*user file write time*” this might be a positive real number or one might be satisfied with an ordinal scale [short, medium, long]. However, in either case the value of the function must be definite. For example the “*user file read time*” might be defined as the time it takes the unit operator to open the document on the field unit plus the time it takes to read and understand the document completely. When it comes to the criteria “*comfort*”, it is not at all clear how the criterion should be defined even if one could agree on and appropriate measuring scale.

In summary: Every uncertain criterion can be defined as having a certain value for a specific action. Therefore every action an uncertain criterion will have a certain value. Thus one must first define the action in which the evaluation is going to take place, only then can one use an uncertain criteria in an evaluation.

4.2.2 Handling Uncertain Criteria

In classical MCDA, once a criterion g is defined (even if it is synthetic in the sense discussed in the previous section), it is assumed that for a given action a the value of $g(a)$ is certain. In UCN this is not the case; the values are dependant on certain actions and limitations.



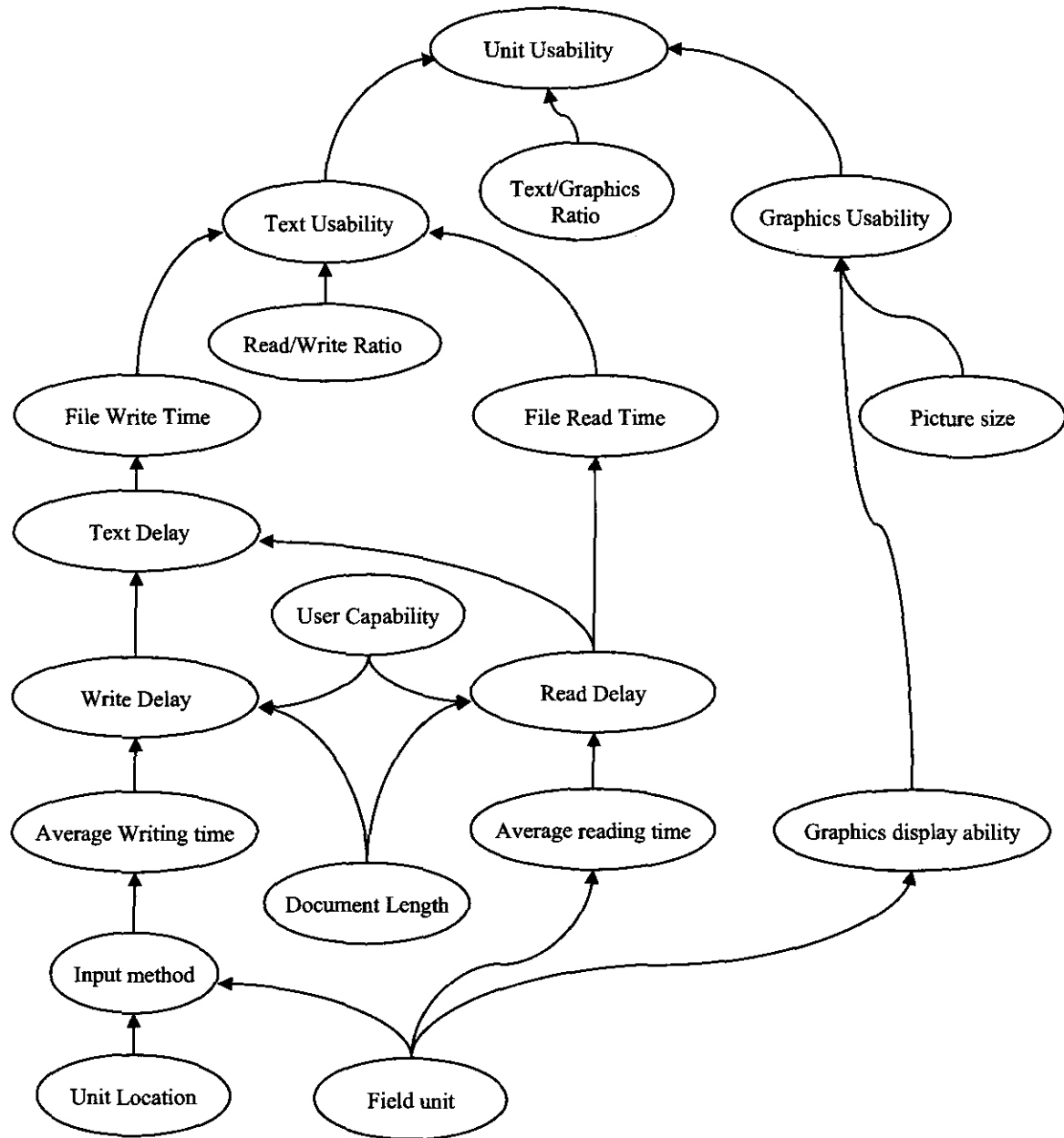


Figure 4-5: UCN for predicting the uncertain criteria in case study

Application: In the case study there are three criteria on which to base a decision about which action one should choose from all pairs <unit type, input method>. These criteria are usability (*user file read time*, *user file write time*), cost and *specification*. For simplicity, one can assume that the values of cost and specification are certain for each possible action. However, *user file read time* and *user file write time* are uncertain. For example, *user file read time* for a specific choice of action will vary according to where the field unit is at the time of file reception (in office, in vehicle or on site).

The UCN should include not just the uncertain criteria but also other factors that can influence the value of a criterion for a given action. Such factors can be thought of as *risk factors*, they often cannot be controlled by the decision-maker. These factors, along with the uncertain criteria themselves, will form the set of nodes in an UCN for predicting the values of the uncertain criteria.

Application: In the WebForce case study the two uncertain criteria *user file read time* and *user file write time* are affected by risk factors *field unit location* and *file size received*. In Figure 4-5 a single UCN that incorporates the uncertain criteria with the factors that impact on them are presented. Notice that the UCN does not include the certain criteria cost and *specification*. The probability tables of the UCN in this case study are relevant for a classic field force dispatch system; most are simply deterministic functions of their parents while others are derived from expert judgement plus a small amount from empirical data.

4.2.3 Determining values for uncertain criteria

To confirm that the approach described above is both practically possible and usable in real applications, one must return to the case study shown in Figure 4-5. In the following section an explanation how the UCN was implemented in the case study will be given.

The UCN was broken up into subsections to ease the explanation of the UCN. It was subdivided into:



- Write Delay
- Read Delay
- Unit usability
- Text usability
- Graphic usability.

Via the simplified versions of a real application of how the UCN functions will be illustrated. The criteria are mapped into $[0, 1]$ intervals to help with the normalization. For the illustration on how the UCN works, some specific actions were chosen. The values are calculated for only the "PDA" field unit (for a complete evaluation, the same has to be done for the Cell Phone and Laptop for this specific action taken). For a complete sensitivity evaluation one has to compute the output values for the whole range of actions (especially for the actions that would fit the real world application best).

Write Delay:

The "*Writing Delay*" criterion describes the time delay when writing a document (task report) of a certain length (in characters) with a certain field unit class at a specific location (either in office or outdoors) by a certain user.

The purpose of the UCN subsection is to determine whether it is possible to write a document on a field unit within the boundaries of the constraints. The UCN node "*Write Delay*" was defined in terms of *Unit location*, *Field unit*, *Input method*, *Average writing time*, *Document length* and *User capability*. The external criteria in the section are the *Document length* and the *User capability* (variables one cannot control, but which can influence the value of criteria for a given action).



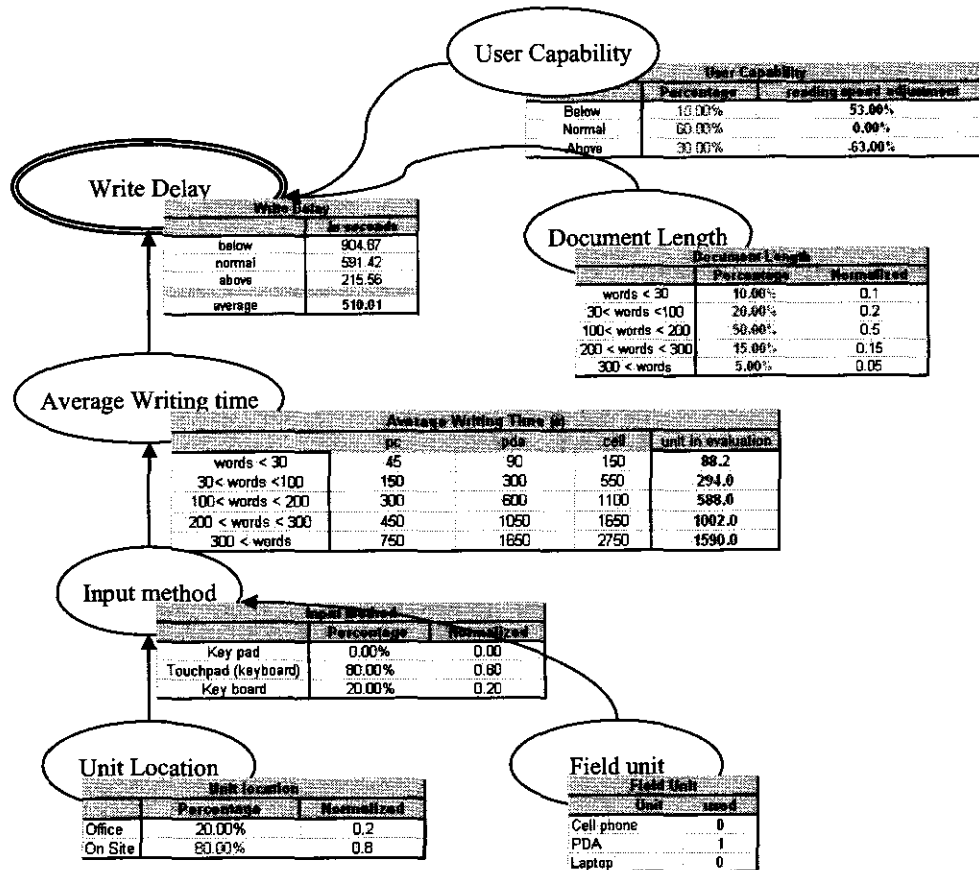


Figure 4-6: UCN - Write Delay node

Read Delay

The “*Read Delay*” criterion describes the delay in time when reading a document (task description) of a certain length (in characters) with a certain field unit class at a specific location (either in office or outdoors) by a certain user.

The purpose of the UCN subsection is to determine whether it is possible to read a document (task description) on a field unit within the boundaries of the constraints. The UCN node, “*Read Delay*” was defined in terms of *Unit location*, *Field unit*, *Average reading time*, *Document length* and *User capability*. The external criteria in the section is the *Document length* and the *User capability* (variables one cannot control, but which can influence the value of criteria for a given action).



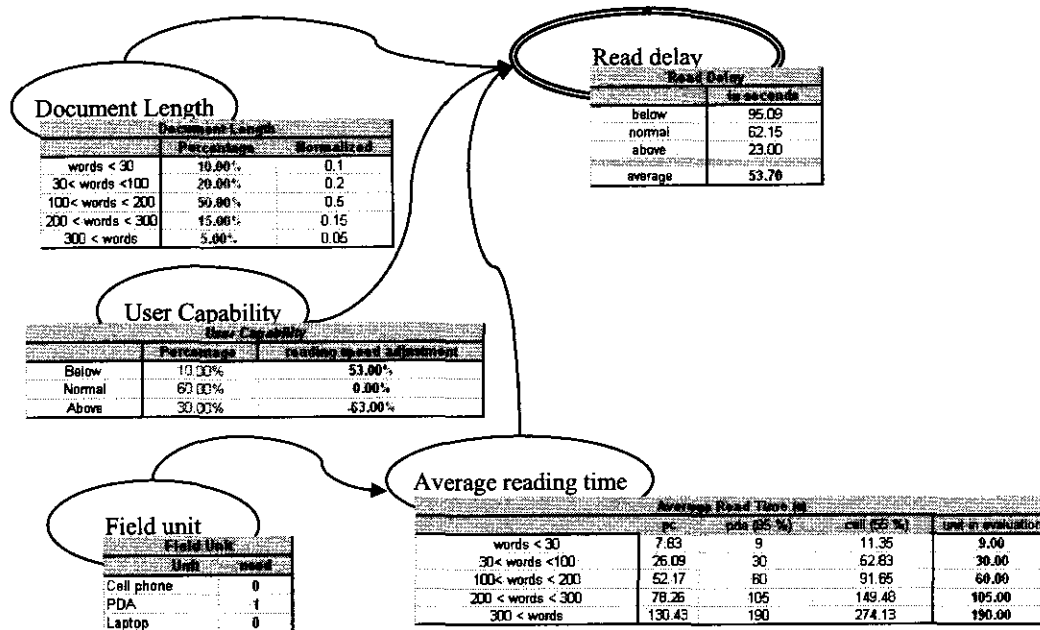


Figure 4-7: UCN - Read Delay node

Text usability

The “*Text usability*” criterion describes the delay in time when reading and writing a document (task description/report) of a certain length (in characters) with certain field unit class at a specific location (either in office or outdoors) by a certain user. The “*Text usability*” criterion is determined by calculating the *File read* and *File write time* and then taking into account the percentage it’s used for a certain task (Read 50%, Write 50% for this experiment).

The purpose of the UCN subsection is to determine the text usability for a certain field unit within the boundaries of the constraints. The UCN node “*Text usability*” was defined in terms of *Write Delay*, *Read Delay*, *Text delay*, *File read time*, *File write time* and *Read/Write ratio*. The external criteria in the section is the *Read/Write ratio* (variable one cannot control, but which can influence the value of criteria for a given action).

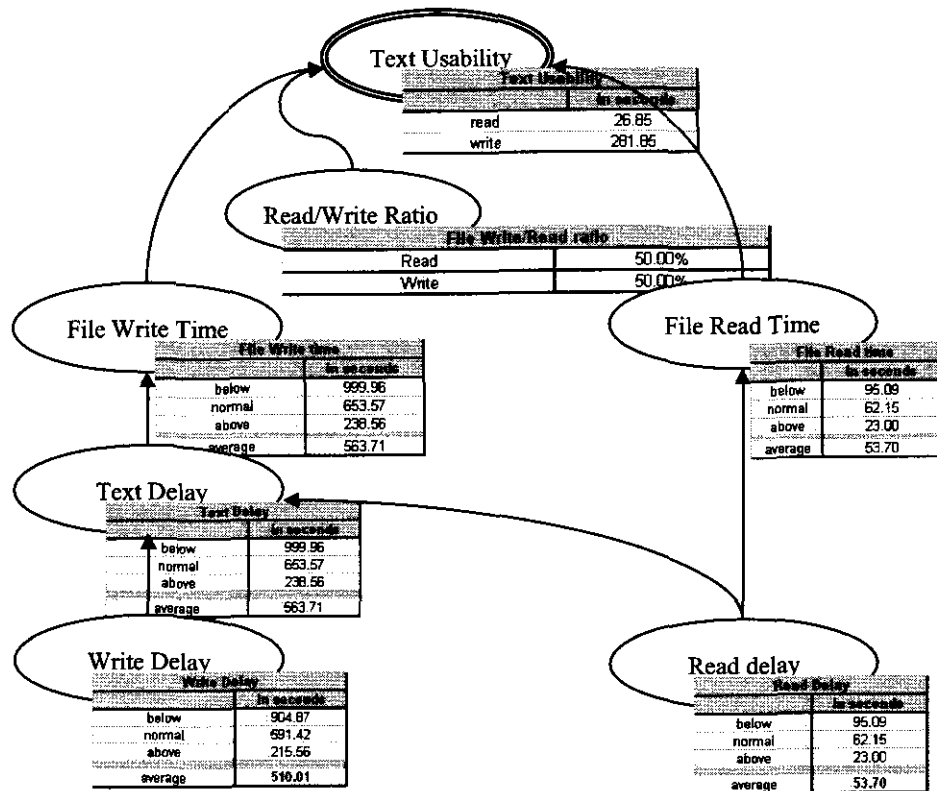


Figure 4-8: UCN - Text Usability

Graphic usability

The “*Graphics usability*” criterion describes the capability in percentage of a specific field unit to utilize a specific picture size. The “*Graphics usability*” is determined by the percentage of time a picture will appear in a task description of a certain size.

The purpose of the UCN subsection is to determine the Graphics usability for a certain field unit within the boundaries of the constraints. The UCN node “*Graphics usability*” was defined in terms of *Field unit*, *Graphics display* and *Picture size*. The external criteria in the section is the *Picture size* (variable one cannot control, but which can influence the value of criteria for a given action).



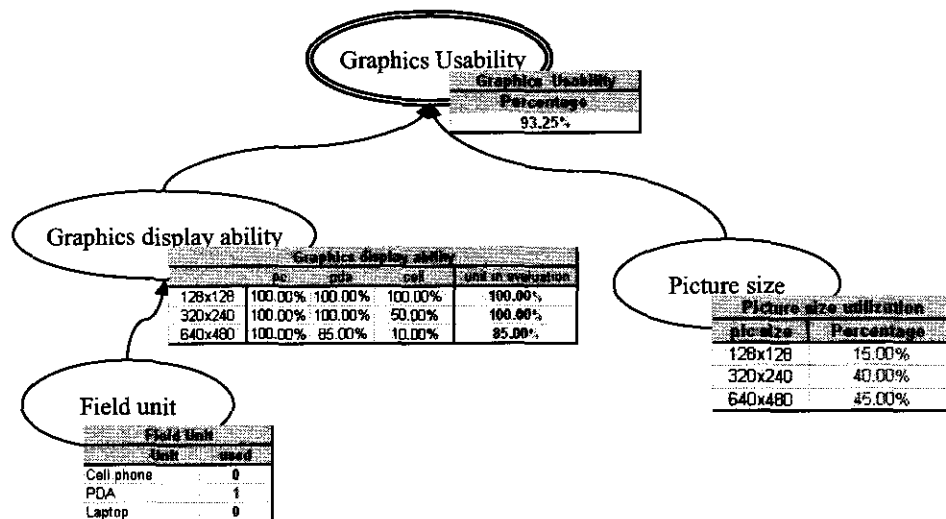


Figure 4-9: UCN - Graphic Usability

Unit usability

The “*Unit usability*” criterion is the output criterion of the complete UCN model. It describes the capability of a certain field unit to cope with certain text and visual effects that could appear in a task description/report under certain working conditions. The final scores that are normalized are sent to the MCDA model for further evaluation. The “*Unit usability*” is determined by the *Text usability* and *Graphics usability* by taking into account the percentage of time text and visual effects will appear in a document (Text 50%, Graphics 50% for this experiment).

The purpose of the UCN subsection is to determine the overall usability of a certain field unit within the boundaries and constraints. The UCN node “*Unit usability*” was defined in terms of *Text usability*, *Text/Graphics ratio* and *graphics usability*. There are no external criteria in the section.

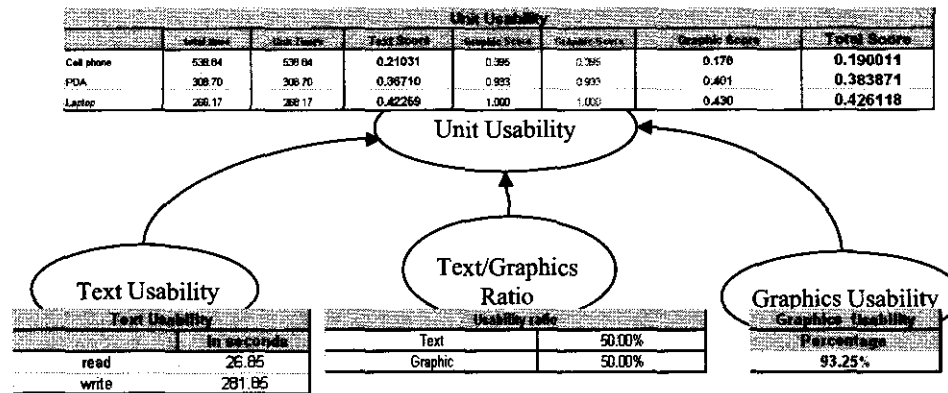


Figure 4-10: UCN - Unit Usability

4.3 Implementing a UCN model in MCDA

The first question to ask is what are the goals or the objective for the evaluation. Next one has to consider the perspective (for example, the regulator as opposed to the developer). Next one asks “questions”, which one thinks of identifying the set of possible actions and then the set of criteria that distinguish these actions. At this point traditional MCDA would simply insist that one define the underlying measures for one’s chosen criteria. This MCDA method would then provide a means of combining the resulting measures for each action and provide a means of ranking the actions as a result.

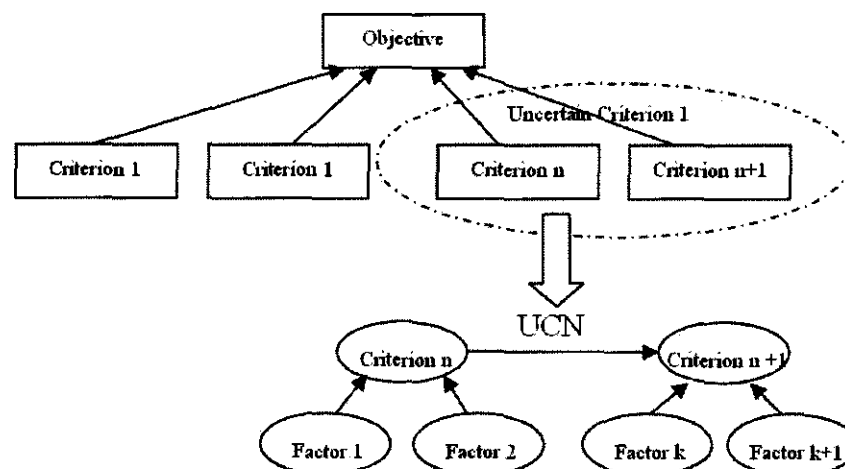


Figure 4-11: How the UCN approach fits into MCDA

The key difference is that while some criteria may be certain, and hence depend on a traditional approach to measurement, many key criteria will require uncertain inference. These criteria will depend on various factors that one has to identify. Having identified the factors as illustrated in the previous section, one uses them to make predictions of the values of the uncertain criteria for the different actions. This can be done by using an UCN. This enables one to compute values for each criterion for a given action and then applying traditional MCDA techniques to combine the values and rank the actions. This process is shown schematically in Figure 4-11.

In the previous example (which builds on the field unit case study), one can use (for simplicity) a crude multi-attribute utility approach. In such an approach each criteria g_i is assumed to be measurable on a ratio scale and each can be mapped into a common interval, e.g. $[0, 1]$ where 0 represents the “worst” value for the criteria and 1 represents the ‘best’ value.

Each criteria g_i is then given a utility weighting u_i that represents the relative importance of each attribute for the given decision problem. The overall “utility” $U(a)$ of an action a is then simply the weighted sum $\sum g_i u_i(a)$. Because this method (unlike usual MCDA methods) provides a complete description of uncertain criteria in terms of their probability distribution, one has a great flexibility in how to use this in calculating $U(a)$. The distributions of uncertain criteria could be used as additional criteria.

4.4 In summary this method consists of the following:

1. Agree on the objective for the decision problem.
2. Make sure one knows from whose perspective the problem must be solved. Thus, identify carefully both the decision maker and the stake holders.
3. Identify the set of possible actions that will form the set of alternatives available.
4. Identify the set of criteria (that is the attributes of actions, which will determine one's choice).



5. Identify any fixed constraint (that is properties of criteria that must be satisfied for any chosen action).
6. Determine which criteria are uncertain (can only be calculated for given action using uncertain inference) and the certain criteria (can be calculated with certainty).
7. For the certain criteria ensure that there are appropriate definitions that enable an unambiguous mapping of actions into a totally ordered set. There is no harm if the ordered set is a simple ordinal scale as long as clear rules are defined for the mapping. If a criterion is vague or complex, it may be necessary to decompose it into lower level attributes. However, all definitions of the certain criteria (including any decomposition) must be done separately from the UCN.
8. For the uncertain criteria, identify the factors that will affect them. There will generally be external factors that cannot be controlled and some internal factor that one can control. Having identified them, construct one or more UCNs for the various actions.
9. As a result of steps 7 and 8 one will be able to calculate a value (within some probability bounds in the case of the uncertain criteria) for each uncertain criterion for a given action. This means traditional MCDA techniques can be applied to combine the values for a given action and then to rank the set of actions. In the case of the uncertain criteria one could, for example, apply values for the most likely as well as the upper and lower bounds. If the result of the MCDA analysis produces a unique "best" action which satisfies all of the defined constraints, then one is done. If not, one will have to relax various constraints or introduce new actions.

4.5 Evaluation Process Conclusion

In real life decision making problems, the criteria used for the evaluation is not always certain. This poses to be a problem when using standard MCDA, because it assumes that all relevant criteria are certain. This problem is solved using a type of UCN network to calculate a value for each uncertain criterion for a given action, thus leaving only certain criteria for given actions. UCNs help one to make predictions about uncertain



factors like the functionality of a proposed system. While this is extremely important, it is only one component of a broader decision making process when there are multiple 'success' factors to consider. In this dissertation the broader decision making context is described and a method for addressing it has been provided.

The "full text" version of steps 4 and 5 of the MCDA model can be found in Appendix D. This includes a full description of how the scoring measurement scales of each criterion were determined.

In the following chapter (the Evaluation Phase), the focus will be on the sensitivity analyses. In this section the effects of score (the scores of the criteria on different levels) will be observed when changing the weights of different criteria.



CHAPTER FIVE

5 Evaluation Phase

In this section the focus will be on the sensitivity of the evaluation module. The interaction of all the criteria will be tested at different levels of criteria. Two types of tests will be conducted:

- A section where the effect on the final score of the field units will be observed when changing the weights of specific level of criteria.
- A section where the effect on the “one level up” score of the field units will be observed when changing the weights of specific level of criteria.

The analysis will be done by increasing the weights of the criteria in question from “0” (minimum) to “1” (maximum) and observing what effect it will have on the score in question. These tests will be conducted on both the MCDA and the UCN models.



5.1 Experimental setup conditions

Date	: 2004-04-01 to 2004-05-30
Time of day	: 9:00 – 12:00 and 14:00 to 16:00
Environment	: North-West University, Potchefstroom Campus, School of Electric & Electronic Engineering offices.
Distance to closest GSM/GPRS tower	: 100m to 200m

5.2 UCN Sensitivity

In the following section a look at the sensitivity of the UCN model in the evaluation model will be viewed. The criteria being evaluated in the UCN are the usability of the three field units. The scores of the *Cell Phone*, *PDA* and *Laptop* in the following section are normalized with respect to each other.

Changes to the ratio of the amount of text/graphics that are used in task descriptions (the files that will be opened on the field units and be displayed on the screens) and the ratio of the amount of reading/writing (the ratio that describes the amount of times a technician will read a task description to the amount times a technician will have to write a task report) will be made.

In Figure 5-1 to Figure 5-3 the axes must be interpreted as follows:

X-axis: 1 to 11 = 0% to 100%

Y-axis: S1 to S11 = 0% to 100%



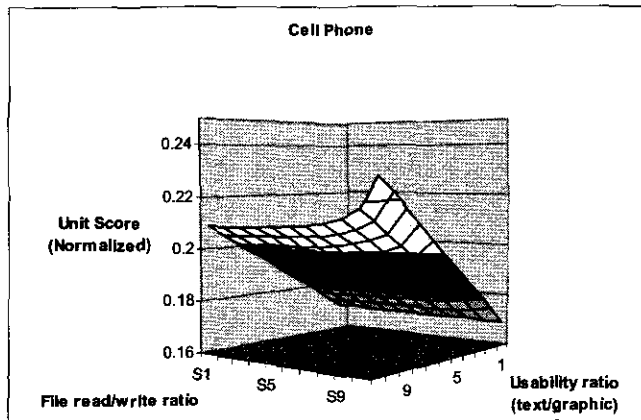


Figure 5-1: UCN (Usability) Sensitivity – Cell Phone

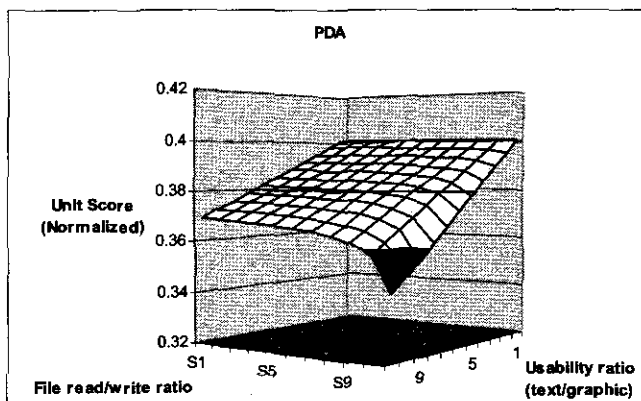


Figure 5-2: UCN (Usability) Sensitivity – PDA

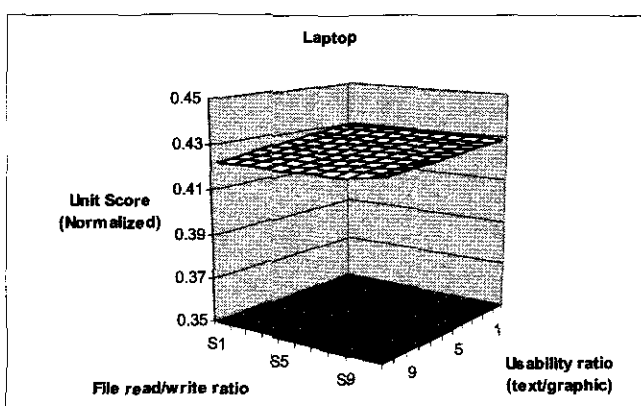


Figure 5-3: UCN (Usability) Sensitivity – Laptop

Table 5-1: UCN (Usability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.17	0.345	0.422
Max	0.229	0.401	0.43

To be able to interpret the three figures on the left one must consider all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the UCN module score.

If the "Usability ratio (text/graphic)" (more graphic is used than text in document) is increased, one can observe that the Cell Phone score increases. This is the logical response; it is easier to read and write on a Cell Phone than it is to interpret a picture on its screen. Because of this, PDA and Laptop loses score. The PDA is more affected by this because the interpretability of graphics is lower on the PDA than on a Laptop.



Figure interpretation:

On the other hand if one increases the “*file read/ write ratio*” (more reading than writing is done), one can observe that the Cell Phone score increases more as the “*file read/ write ratio*” increases.

Once more this is the logical response; while the file write capability on the PDA increases, the writing capability of the Cell Phone decreases (this has no effect on the Laptop). Thus the PDA scores will decrease as the “*file read/ write ratio*” increases and the score of the Cell phone will increase.

Looking at the three graphs in general one can observe that the Laptop is affected least by the “*file read/ write*” and the “*Usability ratio (text/ graphic)*” ratios. Thus from this, one can conclude that the Laptop is less sensitive to the changes, making it the best option for usability in a wide range of applications. Looking at the maximum and minimum scores in Table 5-1, the Laptop is the best option for the usability criteria in the Telkom case study.

In the following section changes to the ratio of the amount of time that the field technician spends indoors (at office) and outdoors (on the road or at task destination) will be made. The following data is presented in Figure 5-4:

Table 5-2: UCN (Usability) Sensitivity 2

	Cell phone	PDA	Laptop
Min	0.154	0.383	0.417
Max	0.195	0.409	0.441

Figure interpretation:

If the “*On site Percentage*” (meaning that the field technician is more in mobile locations than at the office) is increased, the Cell Phone score increases. This is what one would expect from the Cell Phone because it would become more user friendly in mobile



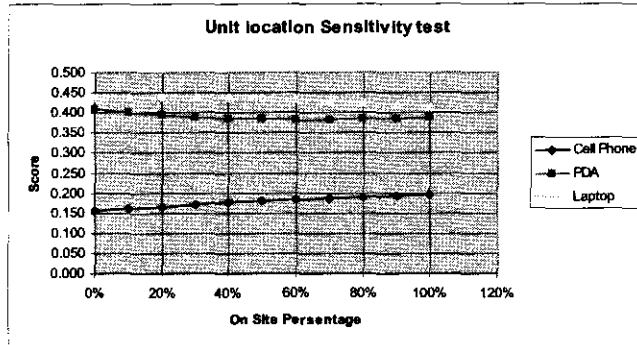


Figure 5-4: UCN (Usability) Sensitivity

locations or easier to use (its usability would become better). By observing the PDA one can see that the score is pulled down by the Cell Phone, but levels out when the field technician is more than 40% on site. On the other hand, the score of the Laptop starts to decrease the

moment the technician is more on location than in the office. The minimum and maximum values can be found in Table 5-2.

This is what one would expect because of the nature of the field units; it is more difficult to work on a Laptop in mobile conditions than in the office. While with the PDA and the Cell Phone, it would not make a big difference on the location of the field unit. The reason why the PDA's score first decreases and then levels out is because the assumption is made that the PDA could make use of an expansion keyboard while in office (this would make the report writing faster and, therefore, the unit more effective).

Conclusion:

Taking a step back and looking at the basic forms of the 3D plots, one can observe that the Laptop is not really affected by the changes that were made to the criteria's weights, therefore the Laptop is not sensitive to changes in aspects of the Usability (UCN) criteria. This makes the Laptop the best option in cases where one struggles to determine the uncertain aspects of this criterion. The difference from minimum to maximum of the Cell Phone and the PDA are both in the same range, thus making them relatively sensitive to changes in aspects of this criterion. Looking at the maximum and minimum scores of the field units, the Laptop is the best option for the Usability criteria followed shortly by the PDA. The Cell Phone dropped out completely when focusing on the Telkom case study requirements.



5.3 MCDA Level-1 Sensitivity

In the following section the sensitivity of the MCDA in the evaluation model will be viewed. The weights of the three level-1 criteria will be changed to see what the effect of this would be on the final score of the field units. The analysis will be done by making the weight of one of the three criteria zero and increasing the weights of the other two criteria from "0" (minimum) to "1" (maximum). This will be done in rotation until all of the criteria have a turn to be zero.

5.3.1 Specification and Cost

In this section the Usability (UCN) criteria will have a weight of zero and the weights of the Specification and Cost criteria would increase from "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* are normalized with respect to each other, therefore, the increase in score of the one field unit will cause a decrease in score of the other field units and *vice versa*. The minimum and maximum values can be found in Table 5-3).

In Figure 5-5 to Figure 5-7 the following axes interpretation must be made:

X-axis: Cost Weight range

1 to 11 = "0" to "1"

Y-axis: Specification Weight range

S1 to S11 = "0" to "1"

Table 5-3: MCDA Level-1 (Specification and Cost) Sensitivity

	Cell phone	PDA	Laptop
Min	0.317	0.372	0.244
Max	0.381	0.374	0.311
Change	0.064	0.002	0.067
Change	18.3%	0.65%	23.9%
Spec	0.318	0.372	0.311
Cost	0.382	0.374	0.244



To be able to interpret the three accompanying figure's, one must consider them simultaneously to make any sense of them. The score that is indicted on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the "*Specification Weight*" is increased from "0" to "1" and the "*Cost Weight*" is kept at "0", one can observe that the Cell Phone's score is at a minimum while the Laptop's score is at a maximum. This can be expected when the Cost criterion (Laptop's weakest criterion/ Cell Phone's strongest criterion) carries no weight and only the Specification criterion carries a weight. Thus the Laptop would score the best because its weakest criterion is cancelled out, while the Cell Phone's score would be at its lowest point because its strongest criterion is cancelled out.

If the "*Cost Weight*" is increased from "0" to "1" and the "*Specification Weight*" is kept at "0", one can observe that the Laptop's score is at a minimum while the Cell Phone's score is at a maximum. This can be expected when the "*Specification*" criterion (Laptop's strongest criterion/ Cell Phone's weakest criterion) has no weight and only the Cost criterion carries a weight. Thus the Laptop's score would be at it lowest point, because it strongest criterion is cancelled out, while the Cell Phone's score would be at its highest point because its weakest criterion is cancelled out.

If the "*Specification Weight*" is increased from "0" to "1" and the "*Cost Weight*" is kept at "1", we can observe that the Cell Phone's score decreases (logarithmic) while the Laptop's score increases (logarithmic). This can be expected when the Cell phone's weakest criterion's weight gets stronger and the Laptop's strongest criterion's weight increases. The turning point from where the plot starts to get linear is at "*Specification Weight*" = "0.3".



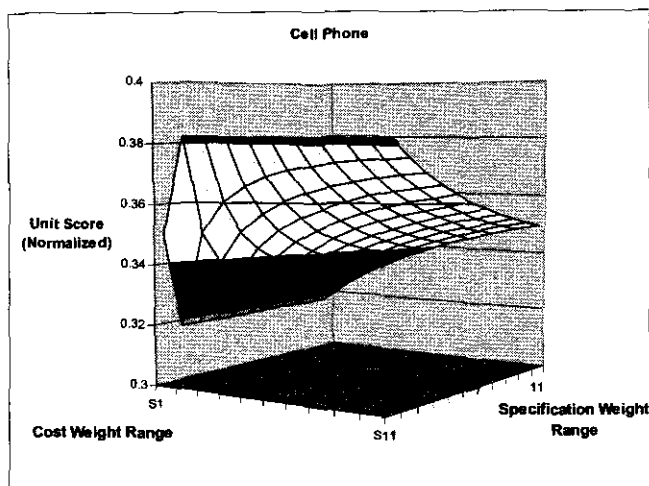


Figure 5-5: MCDA Level-1 (Specification and Cost)
Sensitivity – Cell Phone

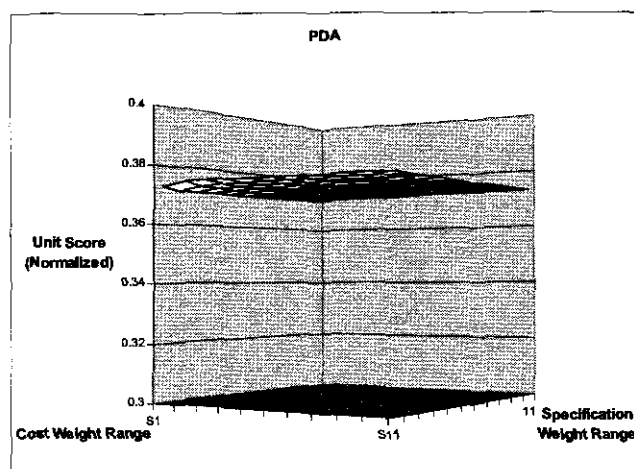


Figure 5-6: MCDA Level-1 (Specification and Cost)
Sensitivity – PDA

If the "*Cost Weight*" is increased from "0" to "1" and the "*Specification Weight*" is kept at "1" in Figure 5-5 to Figure 5-7, one can observe that the Cell Phone's score increases (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected when the Cell Phone's strongest criterion's weight gets stronger and the Laptop's weakest criterion's weight gets weaker. The turning point from where the plot starts to get linear is at "*Cost Weight*" = "0.2".

Conclusion

If one takes a step back and looks at the basic forms of the 3D plots, one can observe that the PDA is not really affected by the changes that were made to the criteria's weights, thus the PDA is not sensitive to changes in Specification and Cost. This makes the PDA the best option

in cases where one struggles to determine the weights for Specification and Cost. The difference from minimum to maximum of the Cell Phone and the Laptop are both in the



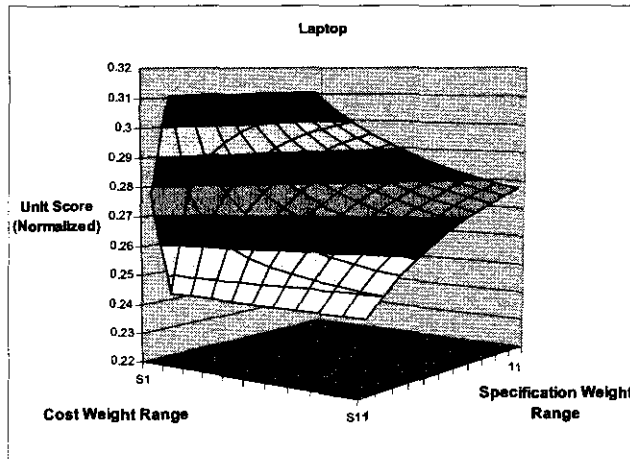


Figure 5-7 : MCDA Level-1 (Specification and Cost)
Sensitivity – Laptop

range of 20%, thus making them relatively sensitive for changes in Specification and Cost weights. Looking at the maximum and minimum scores in Table 5-3, the PDA is the best option for the Cost and Specification criteria, when the Usability criterion isn't important in the Telkom case study.

5.3.2 Specification and Usability (UCN)

In this section the Cost criteria will have a weight of zero and the weights of the Specification and Usability criteria would increase from "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* are normalized with respect to each other, thus the increase in score of the one field unit will cause a decrease in score of the other field units and *vice versa*.

Table 5-4: MCDA Level-1 (Specification and Usability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.190	0.372	0.311
Max	0.318	0.384	0.426
Change	0.128	0.012	0.115
Change	50.3%	3.26%	31.4%
Spec	0.318	0.372	0.311
Usability	0.190	0.384	0.426



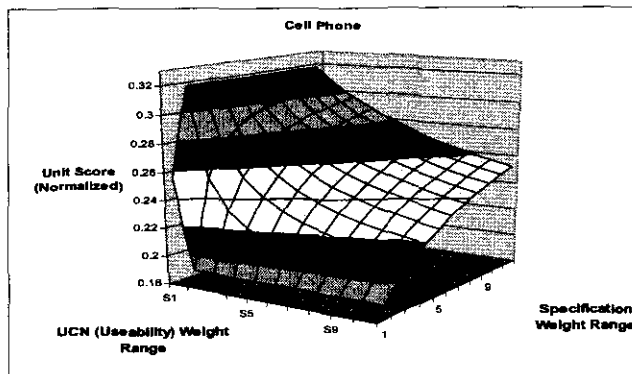


Figure 5-8: MCDA Level-1 (Specification and Usability)
Sensitivity – Cell Phone

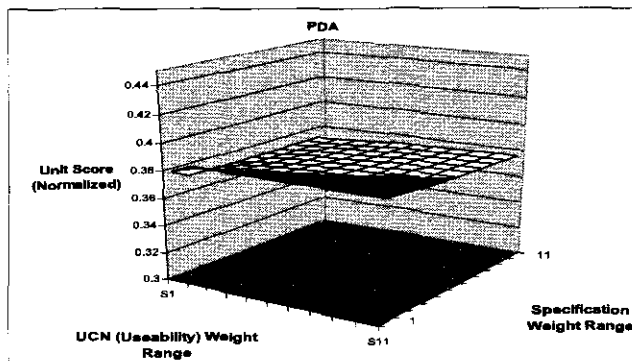


Figure 5-9: MCDA Level-1 (Specification and Usability)
Sensitivity – PDA

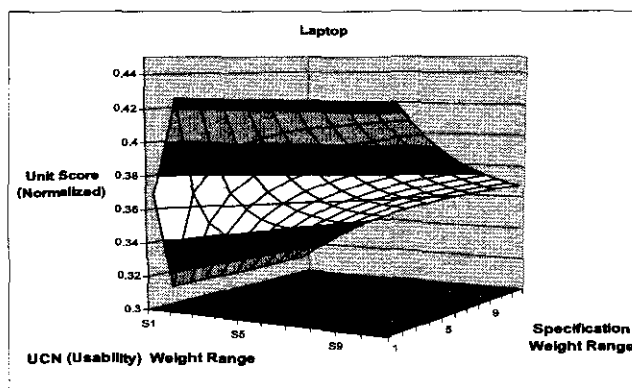


Figure 5-10: MCDA Level-1 (Specification and Usability)
Sensitivity – Laptop

In Figure 5-8 to Figure 5-10 the following axes interpretation must be made:

X-axis: Specification Weight
range

1 to 11 = "0" to "1"

Y-axis: Usability Weight range

S1 to S11 = "0" to "1".

To be able to interpret the three figures on the left one must consider them simultaneously. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the "Specification Weight" is increased for "0" to "1" and the "Usability Weight" is kept at "0", one can observe that the Cell Phone's score is at a maximum while the Laptop's score is at a minimum. This can be expected when the Usability criterion has no weight and only the Specification criterion (Laptop's score is weaker than the Cell Phone's score for this criterion)

carries a weight. Therefore the Laptop's score would be at its lowest point and the Cell Phone's score would be at its highest point.

If the "*Usability Weight*" is increased from "0" to "1" and the "*Specification Weight*" is kept at "0", one can observe that the Cell Phone's score is at a minimum while the Laptop's score is at a maximum. This can be expected when the Specification criterion has no weight and only the Usability criterion (Laptop's score is stronger than the Cell Phone's score for this criterion) carries a weight. Therefore the Laptop's score would be at its highest point and the Cell Phone's score would be at its lowest point.

If the "*Specification Weight*" is increased (Laptop's weakest criterion/ Cell Phone's strongest criterion) from "0" to "1" and the "*Usability Weight*" is kept at "1", one can observe that the Cell Phone's score increases (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected when the Cell Phone's strongest criterion's weight get stronger and the Laptop's weakest criterion's weight gets stronger (bigger). The turning point from where the plot starts to get linear is at "*Specification Weight*" = "0.3".

If the "*Usability Weight*" is increased (Laptop's strongest criterion/ Cell Phone's weakest criterion) from "0" to "1" and the "*Specification Weight*" is kept at "1", one can observe that the Cell Phone's score decreases (logarithmic) while the Laptop's score increases (logarithmic). This can be expected when the Cell phone's weakest criterion's weight gets stronger and the Laptop's strongest criterion's weight gets weaker. The turning point from where the plot starts to get linear is at "*Cost Weight*" = "0.3".

Conclusion

If one views the basic forms of the 3D plots one can observe that the PDA is not really affected by the changes that were made to the criteria's weights, therefore, the PDA is not sensitive for changes in Specification and Usability. This makes the PDA the best option in cases where one struggles to determine the weights for Specification and Usability.



The difference from minimum to maximum of the Cell Phone is 50.3%, while the difference from minimum to maximum of the Laptop is 31.4%. Thus ranking the sensitivity of the field units from best to worst (in order of sensitivity) it would be: PDA, Laptop, and then the Cell Phone. Looking at the maximum and minimum scores in Table 5-4, the PDA is the best option for the Specification and Usability criteria (when the Cost criterion does not matter in the Telkom case study).

5.3.3 Cost and Usability (UCN)

In this section the Specification criteria will have a weight of zero and the weights of the Cost and Usability criteria would increase from "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* in the following section are normalized with respect to each other, therefore the increase in score of the one field unit will cause a decrease in score of the other field units and vice versa.

In Figure 5-11 to Figure 5-13 the following axes interpretation must be made:

X-axis: Cost Weight range

1 to 11 = "0" to "1"

Y-axis: Usability Weight range

S1 to S11 = "0" to "1".

Table 5-5: MCDA Level-1 (Cost and Usability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.190	0.374	0.244
Max	0.382	0.384	0.426
Change	0.192	0.010	0.182
Change	67.1%	2.61%	54.3%
Cost	0.382	0.374	0.244
Usability	0.190	0.384	0.426



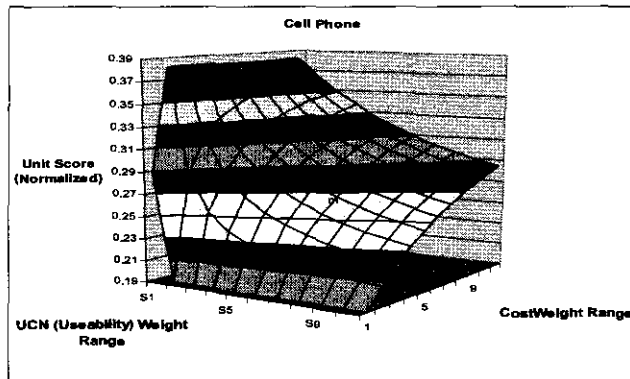


Figure 5-11: MCDA Level-1 (Cost and Usability) Sensitivity

– Cell Phone

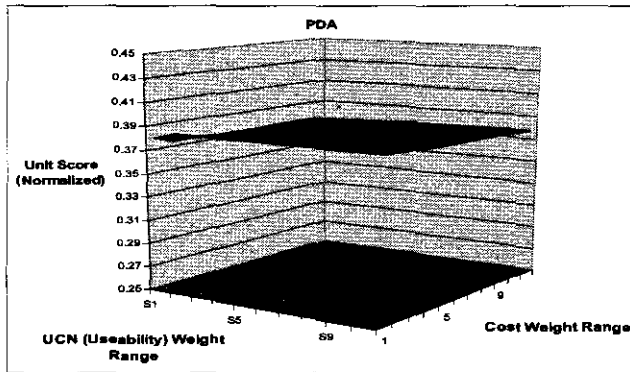


Figure 5-12: MCDA Level-1 (Cost and Usability) Sensitivity

– PDA

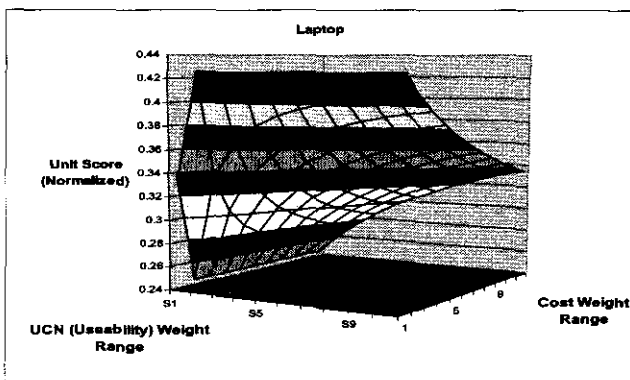


Figure 5-13: MCDA Level-1 (Cost and Usability) Sensitivity

– Laptop

To be able to interpret the three figures on the left one must consider all three simultaneously. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the “*Cost Weight*” is increased from “0” to “1” and the “*Usability Weight*” is kept at “0”, one can observe that the Cell Phone’s score is at a maximum while the Laptop’s score is at a minimum. This can be expected when the Usability criterion has no weight and only the Cost criterion (Laptop’s score is weaker than the Cell Phone’s score for this criterion) carries a weight. Thus the Laptop’s score would be at its lowest point and the Cell Phone’s score would be at its highest point.

If the “*Usability Weight*” is increased from “0” to “1” and the “*Cost Weight*” is kept at “0”,

one can observe that the Cell Phone's score is at a minimum while the Laptop's score is at a maximum. This can be expected when the Cost criterion has no weight and only the Usability criterion (Laptop's score is stronger than the Cell Phone's score for this criterion) carries a weight. Therefore, the Laptop's score would be at its highest point and the Cell Phone's score would be at its lowest point.

If the "*Cost Weight*" (Laptop's weakest criterion/ Cell Phone's strongest criterion) is increased from "0" to "1" and the "*Usability Weight*" is kept at "1", one can observe that the Cell Phone's score increases (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected because the Cell Phone's strongest criterion's weight gets stronger and the Laptop's weakest criterion's weight increases. The turning point from where the plot starts to get linear is at "*Cost Weight*" = "0.4".

If the "*Usability Weight*" (Laptop's strongest criterion/ Cell Phone's weakest criterion) is increased from "0" to "1" and the "*Cost Weight*" is kept at "1", one can observe that the Cell Phone's score decreases (logarithmic) while the Laptop's score increases (logarithmic). This can be expected when the Cell phone's weakest criterion's weight gets stronger and the Laptop's strongest criterion's weight increases. The turning point from where the plot starts to get linear is at "*Cost Weight*" = "0.4".

Conclusion

If one views the basic forms of the 3D plots one can observe that the PDA is not really affected by the changes that were made to the criteria's weights, thus the PDA is not sensitive to changes in Cost and Usability. This makes the PDA the best option in cases where one struggles to determine the weights for Usability and Cost. The difference from minimum to maximum of the Cell Phone is 67.1% while the difference from minimum to maximum of the Laptop is 54.3%. Thus ranking the sensitivity of the field units from good to bad it would be: PDA, Laptop and Cell Phone. Looking at the maximum and minimum scores in Table 5-5, the PDA is the best option for the Cost and Usability criteria (when the Specification criterion does not matter) in the Telkom case study.



5.4 MCDA Level – 2 Sensitivity

In the following section the sensitivity of the level 2 criteria (Processing Capability, Connection capability Portability, Initial Cost, Usage cost and Connection cost) in the MCDA evaluation model will be viewed. The weights of the six level-2 criteria will be changed to see what the effect of this would be respectively on the Specification or Cost scores (level 1 criteria) of the field units. The analysis will be conducted by making the weight of one of the six criteria zero and the increasing the weights of the other two criteria's (that fall under the same level 1 criteria) from "0" (minimum) to "1" (maximum). This will be done in a rotation until all of the criteria have a turn to be zero.

5.4.1 Specification – Processing Capability and Connection Capability

In this section the Portability criteria will have a weight of zero and the weights of the Processing Capability and Connection Capability criteria would increase form "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* in the following section are normalized with respect to each other, therefore the increase in score of the one field unit will cause a decrease insnscore of the other field units and *vice versa*.

Table 5-6: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.180	0.282	0.351
Max	0.366	0.379	0.3441
Change	0.186	0.096	0.090
Change	68.2%	29.1%	22.7%
Proce	0.180	0.397	0.411
Conect	0.366	0.282	0.351



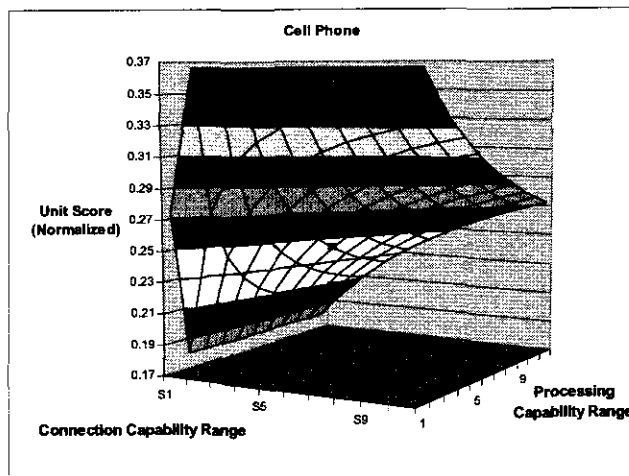


Figure 5-14: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – Cell Phone

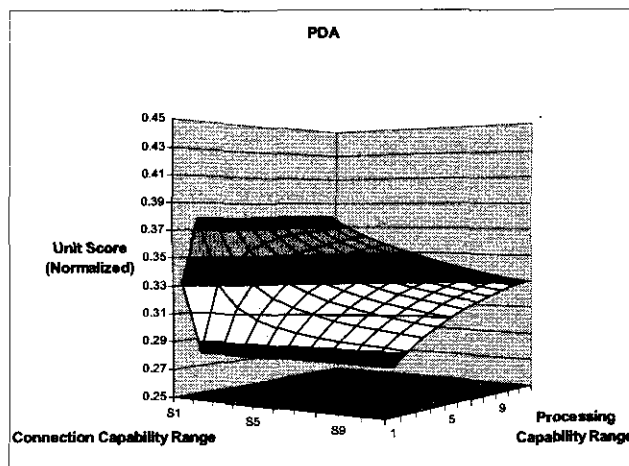


Figure 5-15: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – PDA

In Figure 5-14 to Figure 5-16 the following axes interpretation must be made:

X-axis: Processing Capability weight range

1 to 11 = "0" to "1"

Y-axis: Connection Capability weight range

S1 to S11 = "0" to "1".

To be able to interpret the three figures on the left one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the "Process Capability Weight" is increased from "0" to "1" and the "Connection Capability Weight" is kept at "0", one can observe that the Cell Phone's score is at a

minimum while the Laptop and PDA's scores are at their maximum. This can be expected when the Connection Capability criterion (Laptop and PDA weakest criterion/ Cell Phone's strongest criterion) have no weight and only the Specification criterion carries a weight. Thus the Laptop and PDA would score at their best because their



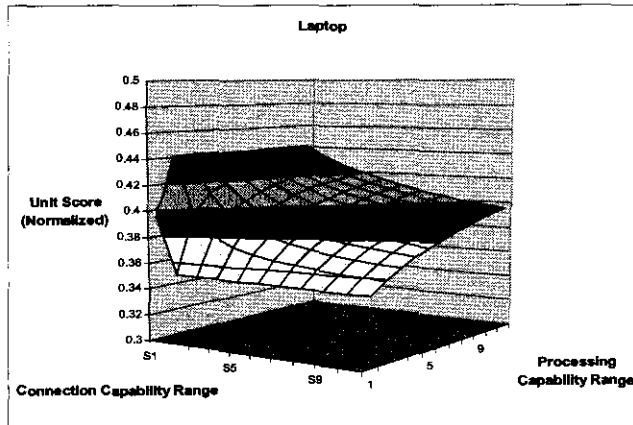


Figure 5-16: MCDA Level-2 (Specification - Processing Capability and Connection Capability) Sensitivity – Laptop

scores are at a minimum while the Cell Phone's score is at a maximum. This can be expected when the Processing Capability criterion (Laptop and PDA's strongest criterion/ Cell Phone's weakest criterion) has no weight in the evaluation and only the connection Capability criterion carries a weight. Thus the Laptop and PDA scores would be at their lowest point (because it strongest criterion is cancelled out), while the Cell Phone's score would be at their highest point (because its weakest criterion is cancelled out).

If the "*Processing Capability Weight*" is increased from "0" to "1" and the "*Connection Capability Weight*" is kept at "1", one can observe that the Cell Phone's score decreases (logarithmic) while the Laptop and PDA scores increase (logarithmic). This can be expected when the Cell Phone's weakest criterion's weight increases and the Laptop and PDA's strongest criterion's weight get stronger (bigger). The scores that are lost by the Cell Phone as the "*Processing Capability Weight*" increase are divided into 51.8% (for the PDA) and a 48.2% (for Laptop) ratio. The turning point from where the plot starts to get linear is at "*Processing Capability Weight*" = "0.4".

$$0.045 \text{ (Laptop increase / 48.2\%)} + 0.048 \text{ (PDA increase / 51.2 \%)} = 0.093 \text{ (Cell Phone decrease).}$$



If the "*Connection Capability Weight*" is increased from "0" to "1" and the "*Processing Capability Weight*" is kept at "1", one can observe that the Cell Phone's score increases (logarithmic) while the Laptop and PDA's scores decrease (logarithmic). This can be expected when the Cell Phone's strongest criterion's weight gets stronger and the Laptop and PDA's weakest criterion's weight gets stronger.). The score that is gained by the Cell Phone as the "*Connection Capability Weight*" increase is taken as 51.8% from the PDA and 48.2% from the Laptop. The turning point from where the plot starts to get linear is at "*Connection Capability Weight*" = "0.2".

$$0.045 (\text{Laptop decrease} / 48.2\%) + 0.048 (\text{PDA decrease} / 51.2\%) = 0.093 (\text{Cell Phone increase}).$$

Conclusion

If one views the basic forms of the 3D plots one can observe that the PDA (29.1% change) and Laptop (22.7% change) are almost equally affected by the changes that were made to the criteria's weights, where the Cell Phone (68.2% change) is affected 2 to 3 times more. Therefore the Cell Phone is the most sensitive to changes in these criteria while the PDA is the least sensitive making it the best option when one is not completely sure of the weights that should be applied to these criteria. Looking at the maximum and minimum scores in Table 5-6, the PDA is the best option for the Processing and Connection Capability criteria (when the Portability criterion does not matter in the Telkom case study).

5.4.2 Specification – Processing Capability and Portability

In this section the Connection Capability criteria will have a weight of zero and the weights of the Processing Capability and Portability criteria would increase from "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* are normalized with respect to each other, thus the increase in score of the one field unit will cause a decrease in score of the other field units and *vice versa*.



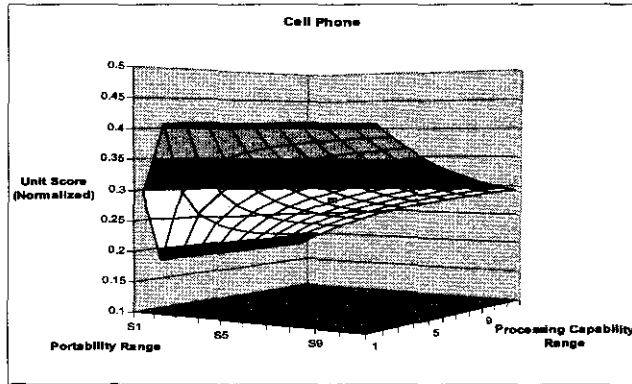


Figure 5-17: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – Cell Phone

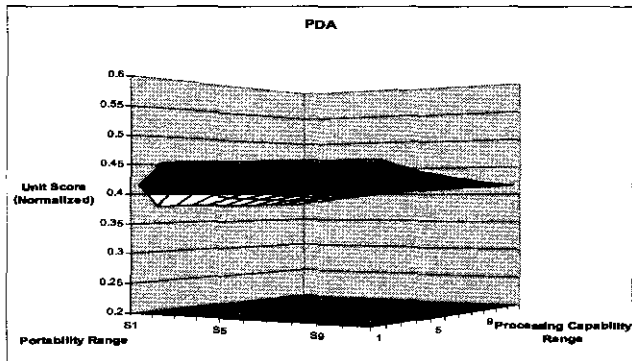


Figure 5-18: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – PDA

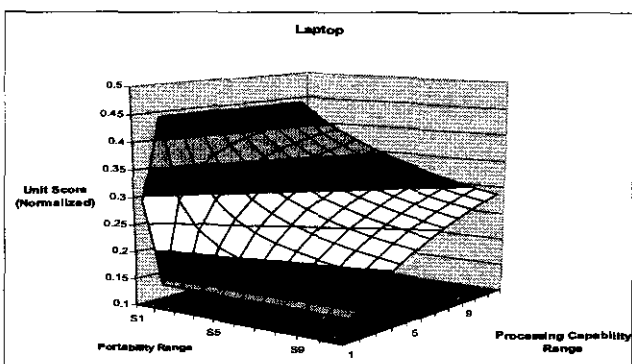


Figure 5-19: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity – Laptop

In Figure 5-17 to Figure 5-19 the following axes interpretation must be made:

X-axis: Processing Capability

Weight range

1 to 11 = "0" to "1"

Y-axis: Portability Weight range

S1 to S11 = "0" to "1".

Table 5-7: MCDA Level-2 (Specification - Processing Capability and Portability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.180	0.379	0.140
Max	0.407	0.453	0.441
Change	0.229	0.075	0.302
Change	77.3%	18.0%	104%
Proce	0.180	0.397	0.411
Portabil	0.407	0.453	0.140

To be able to interpret the three figures on the left one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).



Figure interpretation:

If the "*Process Capability Weight*" is increased from "0" to "1" and the "*Portability Weight*" is kept at "0", one can observe that the Cell Phone and PDA's scores are at a minimum while the Laptop's score is at its maximum. This can be expected when the Portability criterion (Laptop's weakest criterion/Cell Phone and PDA's strongest criterion) have no weight and only the Processing criterion carries a weight. Thus the Laptop would score at its best because its weakest criterion is cancelled out, while the Cell Phone and PDA's scores would be at its lowest point because its strongest criterion is cancelled out.

If the "*Portability Weight*" is increased from "0" to "1" and the "*Process Capability Weight*" is kept at "0", one can observe that the Laptop's score is at a minimum while the Cell Phone and PDA's scores are at a maximum. This can be expected when the Processing Capability criterion (Laptop's strongest criterion/Cell Phone and PDA's weakest criterion) has no weight in the evaluation and only the connection Portability carries a weight. Thus the Laptop and PDA scores would be at their lowest point (because their strongest criterion is cancelled out), while the Cell Phone's score would be at its highest point (because its weakest criterion is cancelled out).

If the "*Processing Capability Weight*" is increased from "0" to "1" and the "*Portability Weight*" is kept at "1", one can observe that the Cell Phone and PDA's scores decrease (logarithmic) while the Laptop's score increases (logarithmic). This can be expected when the Cell Phone and PDA's weakest criterion's weights increase and the Laptop's strongest criterion's weight increases. The scores that are lost by the Cell Phone (75.2%) and PDA (24.8%) as the "*Processing Capability Weight*" increase are added to the Laptop's score. The turning point from where the plot starts to get linear is at "*Processing Capability Weight*" = "0.4".

$$0.113 \text{ (Cell Phone decrease / 75.2\%)} + 0.037 \text{ (PDA decrease / 24.8 \%)} = 0.150 \text{ (Laptop increase).}$$



If the "*Portability Weight*" is increased from "0" to "1" and the "*Processing Capability Weight*" is kept at "1", we can observe that the Cell Phone and PDA's scores increases (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected because when the Cell phone and PDA's strongest criterion's weight increases and the Laptop's weakest criterion's weight increases. The scores that are gained by the Cell Phone and PDA as the "*Portability Weight*" increase is taken from the Laptop score. The turning point from where the plot starts to get linear is at "*Portability Weight*" = "0.4".

$$0.150 \text{ (Laptop decrease)} = 0.037 \text{ (PDA increase / 51.2 \%)} + 0.113 \text{ (Cell Phone increase/ 48.8\%)}$$

Conclusion

If one takes a step back and look at the basic forms of the 3D plots one can observe that the PDA's change of 18 % is very low compared to the Cell Phones 77.3% and the Laptops 104%. Thus the PDA is the least sensitive to changes in these criteria (making it the best option when one is not completely sure of the weights that should be applied to these criteria). On the other hand the Cell phone and Laptop is sensitive because of it's big differences in score between the processing capability and the Portability.

NB: the Laptops score for portability lies within the problem that the Laptop has with a permanent GPRS connection. The unit can't go into hibernate or close the screen of Laptop (it loses the GPRS connection, making this type of connection expensive) to save battery live (only lasts between 2 to 3 hours with the unit on).

Looking at the maximum and minimum scores in Table 5-7 the PDA is the best option for the Processing capability and Portability criteria (when the Connection Capability criterion does not matter in the Telkom case study).



5.4.3 Specification – Connection Capability and Portability

In this section the Process Capability criteria will have a weight of zero and the weights of the Connection Capability and Portability criteria would increase from “0” to “1”. The scores of the *Cell Phone*, *PDA* and *Laptop* are normalized with respect to each other thus the increase in score of the one field unit will cause a decrease in score of the other field units and vice versa.

In Figure 5-20 to Figure 5-22 the following axes interpretation must be made:

X-axis: Connection Capability Weight range

1 to 11 = “0” to “1”

Y-axis: Portability Weight range

S1 to S11 = “0” to “1”

Table 5-8: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity

	Cell phone	PDA	Laptop
Min	0.366	0.282	0.140
Max	0.407	0.453	0.351
Change	0.041	0.0171	0.212
Change	10.5%	46.5%	86.3%
Conect	0.366	0.282	0.351
Portabil	0.407	0.453	0.140

To be able to interpret the three figures on the next page one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the “*Connection Capability Weight*” is increased from “0” to “1” and the “*Portability Weight*” is kept at “0”, one can observe that the Cell Phone and PDA’s scores are at a



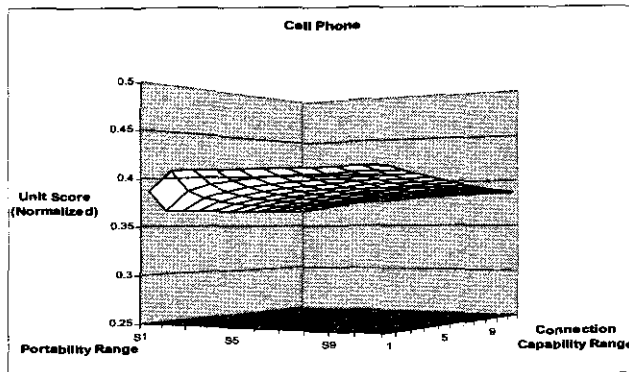


Figure 5-20: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity – Cell Phone

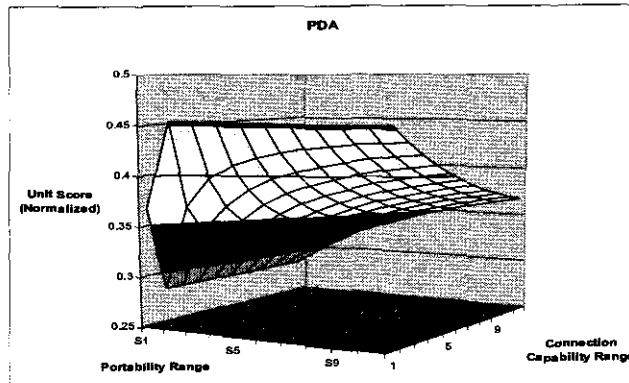


Figure 5-21: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity – PDA

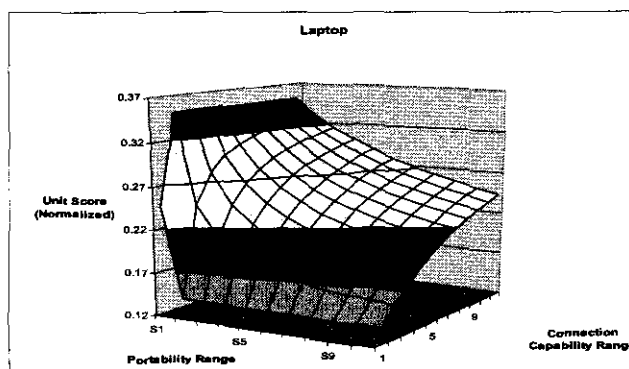


Figure 5-22: MCDA Level-2 (Specification - Connection Capability and Portability) Sensitivity – Laptop

minimum while the Laptop's score is at its maximum. This can be expected when the Portability criterion (Laptop's weakest criterion/Cell Phone and PDA's strongest criterion) has no weight and only the Connection criterion carries a weight. Thus the Laptop would score at its best because its weakest criterion is cancelled out, while the Cell Phone and PDA's scores would be at their lowest point because their strongest criterion are cancelled out.

If the "*Portability Weight*" is increased from "0" to "1" and the "*Connection Capability Weight*" is kept at "0", one can observe that the Laptop's score is at a minimum while the Cell Phone and PDA's scores are at a maximum. This can be expected when the Processing Capability criterion (Laptop's strongest criterion/ Cell Phone and PDA's weakest criterion) has no weight in the evaluation

and only the Portability criterion carries a weight. Therefore the Cell Phone and PDA's scores would be at their highest point (because their weakest criterion is cancelled out), while the Laptop's score would be at its lowest point (because its strongest criterion is cancelled out).

If the "*Connection Capability Weight*" is increased from "0" to "1" and the "*Portability Weight*" is kept at "1", one can observe that the change of the Cell Phone is almost nothing, the PDA's scores decrease (logarithmic) while the Laptop's score increases (logarithmic). This can be expected because the PDA's weakest criterion's weight gets stronger and the Laptop's strongest criterion's weight get stronger. The scores that are lost by the Cell Phone (19.2%) and PDA (80.8%) as the "*Connection Capability Weight*" increase are added to the Laptop's score. The turning point from where the plot starts to get linear is at "*Processing Capability Weight*" = "0.4".

$$0.020 \text{ (Cell Phone decrease / 19.2\%)} + 0.085 \text{ (PDA decrease / 80.8 \%)} = 0.105 \text{ (Laptop increase)}.$$

If the "*Portability Weight*" is increased from "0" to "1" and the "*Connection Capability Weight*" is kept at "1", one can observe that the Cell Phone (almost nothing) and PDA's scores increase (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected when the Cell Phone and PDA's strongest criterion's weight gets stronger and the Laptop's weakest criterion's weight gets stronger. The scores that are gained by the Cell Phone and PDA as the "*Portability Weight*" increases, are taken from the Laptop score. The turning point from where the plot starts to get linear is at "*Portability Weight*" = "0.4".

$$0.105 \text{ (Laptop decrease)} = 0.085 \text{ (PDA increase / 51.2 \%)} + 0.020 \text{ (Cell Phone increase)}.$$

Conclusion

If one views the basic forms of the 3D plots one can observe that the Cell Phone's score change of 10.5 % is very low compared to the PDA (46.5%) and the Laptop (86.3%).



Therefore the Cell Phone is the least sensitive to changes in these criteria (making it the best option when one is not completely sure of the weights that should be applied to these criteria). On the other hand, the Cell Phone is almost half as sensitive as the Laptop. Looking at the maximum scores in Table 5-8, the PDA should be best option for the Processing capability and Portability criteria (when the Connection Capability criterion does not matter in the Telkom case study). Taking into consideration that the Cell Phone maximum score is only slightly lower (0.046) than the maximum score of the PDA but the Cell Phone's minimum score is somewhat bigger (0.082) than the PDA's minimum, both the PDA and the Cell Phone can be recommended as the winner of this criterion.

5.4.4 Cost – Initial Cost and Usage Cost

In this section the Connection Cost criteria will have a weight of zero and the weights of the Usage Cost and Initial Cost criteria would increase from “0” to “1”. The scores of the *Cell Phone*, *PDA* and *Laptop* in the following section are normalized with respect to each other, therefore, the increase in score of the one field unit will cause a decrease in score of the other field units an *vice versa*.

Table 5-9: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity

	Cell phone	PDA	Laptop
Min	0.333	0.333	0.066
Max	0.479	0.455	0.333
Change	0.146	0.122	0.268
Change	35.9%	30.9%	134%
Initial	0.479	0.455	0.066
Usage	0.333	0.333	0.333



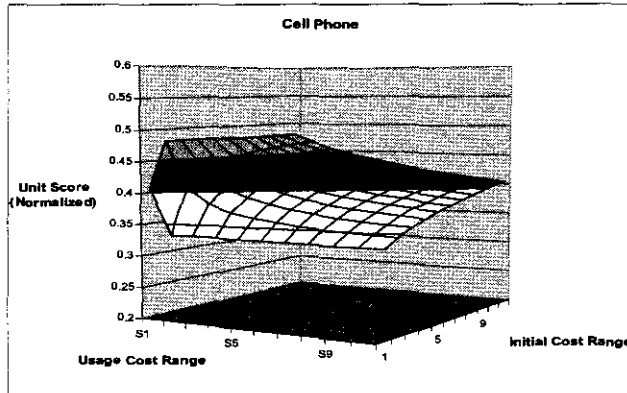


Figure 5-23: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity – Cell Phone

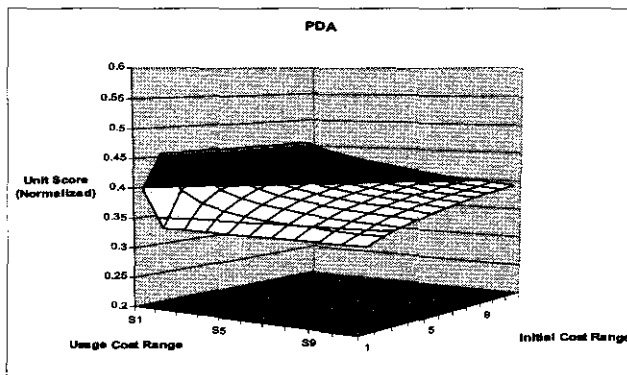


Figure 5-24: MCDA Level-2 (Cost – Initial Cost and Usage Cost) Sensitivity – PDA

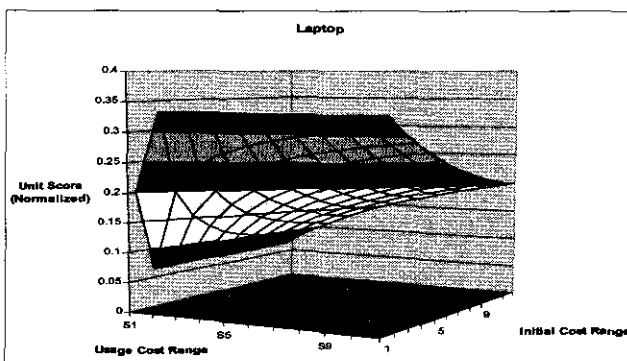


Figure 5-25: MCDA Level-2 (Cost – Initial Cost and Usage Cost) – Laptop

In Figure 5-23 to Figure 5-25 the following axes interpretation must be made:

X-axis: Initial Cost Capability

Weight range

1 to 11 = "0" to "1"

Y-axis: Usage Cost Weight range

S1 to S11 = "0" to "1".

To be able to interpret the three figures one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the "Initial Cost Weight" is increased from "0" to "1" and the "Usage Cost Weight" is kept at "0", one can observe that the Cell Phone and PDA's scores are at a maximum while the Laptop's score is at its minimum. This can be expected when the Usage Cost criterion (Laptop's strongest criterion/



Cell Phone and PDA's weakest criterion) has no weight and only the Initial cost criterion carries a weight. Thus the Laptop would score at its worst because its strongest criterion is cancelled out, while the Cell Phone and PDA's scores would be at their highest point because their weakest criterion is cancelled out.

If the "*Usage Cost Weight*" is increased from "0" to "1" and the "*Initial Cost Weight*" is kept at "0", one can observe that the Laptop's scores are at a maximum while the Cell Phone and PDA's score is at a minimum. This can be expected when the Initial Cost criterion (Laptop's weakest criterion/ Cell Phone and PDA's strongest criterion) has no weight in the evaluation and only the Usage Cost criterion carries a weight. Thus the Cell Phone and PDA's scores would be at their lowest point (because their strongest criterion is cancelled out), while the Laptop's score would be at its highest point (because its weakest criterion is cancelled out).

If the "*Initial Cost Weight*" is increased from "0" to "1" and the "*Usage Cost Weight*" is kept at "1", one can observe that the Cell Phone and PDA's scores increase (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected when the Cell Phone and PDA's strongest criterion's weight get stronger and the Laptop's weakest criterion's weight get stronger. The score that are lost by the Cell Phone (54.5%) and PDA (45.5%) as the "*Initial Cost Weight*" increases are added to the Laptop's score. The turning point from where the plot starts to get linear is at "*Initial cost Weight*" = "0.3

$$0.134 \text{ (Laptop decrease)} = 0.073 \text{ (Cell Phone increase / 54.5\%)} + 0.061 \text{ (PDA increase / 45.5 \%)}.$$

If "*Usage Weight*" is increased from "0" to "1" and the "*Initial Cost Weight*" is kept at "1", one can observe that the Cell Phone and PDA's scores decrease (logarithmic) while the Laptop's score increases (logarithmic). This can be expected when the Cell Phone and PDA's weakest criterion's weight increases and the Laptop's strongest criterion's weight increases. The scores that are lost by the Cell Phone and PDA as the "*Usage cost*



Weight" increase are added to the Laptop score. The turning point from where the plot starts to get linear is at "*Usage Cost Weight*" = "0.3".

$$0.061 \text{ (PDA decrease / 45.5 \%)} + 0.073 \text{ (Cell Phone decrease / 54.5\%)} = 0.134 \text{ (Laptop increase).}$$

Conclusion

If views the basic forms of the 3D plots, one can observe that the Cell Phone (35.9%) and the PDA's (30.9%) scores changes are low compared to the Laptops score change of 134%. Thus the Cell Phone and PDA are less sensitive to changes in these criteria (making them the better option when one is not completely sure of the weights that should be applied to usage and initial cost criteria). Looking at the maximum scores in Table 5-9 the Cell Phone should be the best option for the Initial Cost and Usage cost criteria (when the Connection Cost criterion does not matter in the Telkom case study).

5.4.5 Cost – Initial Cost and Connection Cost

In this section the Usage Cost criteria will have a weight of zero and the weights of the Connection Cost and Initial Cost criteria would increase form "0" to "1". The scores of the *Cell Phone*, *PDA* and *Laptop* are normalized with respect to each other, therefore the increase in score of the one field unit will cause a decrease in score of the other field units and *vice versa*.

Table 5-10: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity

	Cell phone	PDA	Laptop
Min	0.333	0.333	0.066
Max	0.479	0.455	0.333
Change	0.146	0.122	0.268
Change	35.9%	30.9%	134%
Initial	0.479	0.455	0.066
Conect	0.333	0.333	0.333



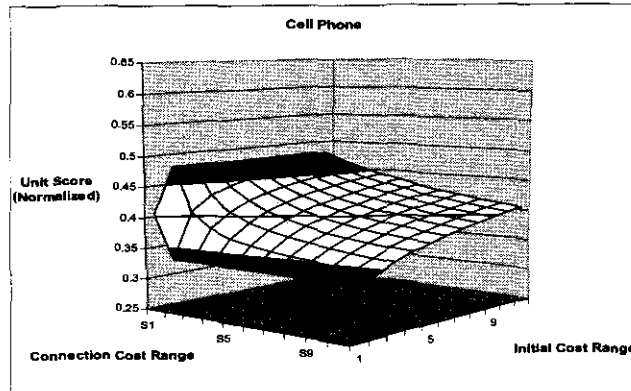


Figure 5-26: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity – Cell Phone

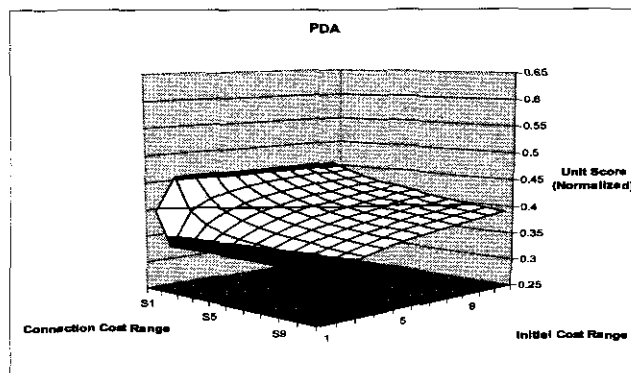


Figure 5-27: MCDA Level-2 (Cost – Initial Cost and Connection Cost) Sensitivity – PDA

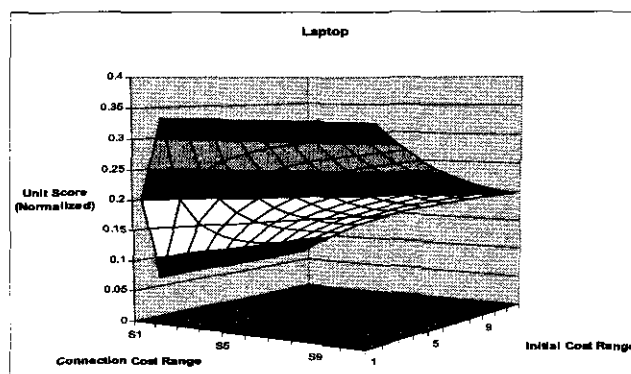


Figure 5-28: MCDA Level-2 (Cost – Initial Cost and Connection Cost) – Laptop

In Figure 5-26 to Figure 5-28 the following axes interpretation must be made:

X-axis: Initial Cost Capability

Weight range

1 to 11 = "0" to "1"

Y-axis: Connection Cost Weight range

S1 to S11 = "0" to "1".

To be able to interpret the three figures on the left one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).

Figure interpretation:

If the "Initial Cost Weight" is increased from "0" to "1" and the "Connection Cost Weight" is kept at "0", one can observe that the Cell Phone and PDA's scores are at a maximum while the Laptop's score is at its minimum. This can be expected when the Connection Cost criterion (Laptop's strongest



criterion/ Cell Phone and PDA's weakest criterion) has no weight and only the Initial cost criterion carries a weight. Therefore the Laptop would score at its worst because its strongest criterion is cancelled out, while the Cell Phone and PDA's scores would be at their highest point because their weakest criterion is cancelled out

If the "*Connection Cost Weight*" is increased from "0" to "1" and the "*Initial Cost Weight*" is kept at "0", one can observe that the Laptop's score is at a maximum while the Cell Phone and PDA's score is at a minimum. This can be expected when the Initial Cost criterion (Laptop's weakest criterion/ Cell Phone and PDA's strongest criterion) has no weight in the evaluation and only the Connection Cost criterion carries a weight. Thus the Cell Phone and PDA's scores would be at their lowest point (because its strongest criterion is cancelled out), while the Laptop's score would be at its highest point (because its weakest criterion is cancelled out).

If the "*Initial Cost Weight*" is increased from "0" to "1" and the "*Connection Cost Weight*" is kept at "1", one can observe that the Cell Phone and PDA's scores increase (logarithmic) while the Laptop's score decreases (logarithmic). This can be expected when the Cell Phone and PDA's strongest criterion's weight get stronger and the Laptop's weakest criterion's weight get stronger. The scores that are lost by the Cell Phone (54.5%) and PDA (45.5%) as the "*Initial Cost Weight*" increase are added to the Laptop's score. The turning point from where the plot starts to get linear is at "*Initial Cost Weight*" = "0.3".

$$0.134 \text{ (Laptop decrease)} = 0.073 \text{ (Cell Phone increase / 54.5\%)} + 0.061 \text{ (PDA increase / 45.5\%)}$$

If the "*Connection Weight*" is increased from "0" to "1" and the "*Initial Cost Weight*" is kept at "1", one can observe that the Cell Phone and PDA's scores decrease (logarithmic) while the Laptop's score increases (logarithmic). This can be expected because when the Cell Phone and PDA's weakest criterion's weight gets stronger and the Laptop's strongest criterion's weight gets stronger. The scores that are lost by the Cell Phone and



PDA as the “*Connection cost Weight*” increase are added to the Laptop score. The turning point from where the plot starts to get linear is at “*Connection Cost Weight*” = “0.3”.

$$0.061 \text{ (PDA decrease / 45.5 \%)} + 0.073 \text{ (Cell Phone decrease / 54.5\%)} = 0.134 \text{ (Laptop increase).}$$

Conclusion

If one views the basic forms of the 3D plots one can observe that the Cell Phone's (35.9%) and the PDA (30.9%) changes are low compared to the Laptops change of 134%. Therefore the Cell Phone and PDA are less sensitive to changes in these criteria (making them the better option when one is not completely sure of the weights that should be applied to these criteria). Looking at the maximum scores in Table 5-10, the Cell Phone should be the best option for the Initial Cost and Connection cost criteria (when the Usage Cost criterion does not matter in the Telkom case study).

5.4.6 Cost – Usage Cost and Connection Cost

In this section the Initial Cost criteria will have a weight of zero and the weights of the Connection Cost and Usage Cost criteria would increase from “0” to “1”. The scores of the *Cell Phone*, *PDA* and *Laptop* in the following section are normalized with respect to each other therefore the increase in score of the one field unit will cause a decrease in score of the other field units an *vice versa*.

Table 5-11: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity

	Cell phone	PDA	Laptop
Min	0.333	0.333	0.333
Max	0.333	0.333	0.333
Change	0	0	0
Change	0%	0%	0%
Usabe	0.333	0.333	0.333
Conect	0.333	0.333	0.333



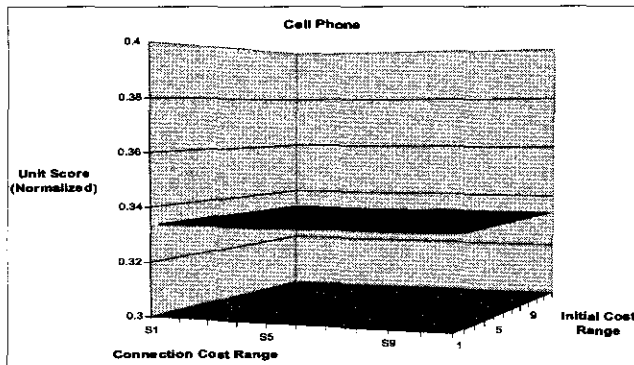


Figure 5-29: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity – Cell Phone

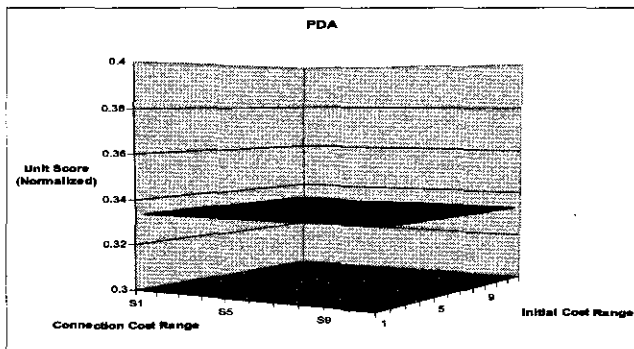


Figure 5-30: MCDA Level-2 (Cost – Connection Cost and Usage Cost) Sensitivity – PDA

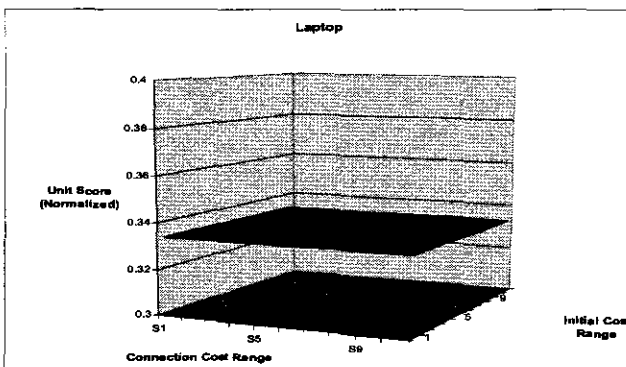


Figure 5-31: MCDA Level-2 (Cost – Connection Cost and Usage Cost) – Laptop

In Figure 5-29 to Figure 5-31 the following axes interpretation must be made:

X-axis: Usage Cost Capability
Weight range

1 to 11 = "0" to "1"

Y-axis: Connection Cost Weight
range

S1 to S11 = "0" to "1".

To be able to interpret the three figures on the left one must look at all three simultaneously to make any sense of them. The score that is indicated on the Z-axis is the Evaluation module score (final score).

5.5 MCDA Single Criteria Sensitivity (on final score)

In the following section the focus will be on the sensitivity of the MCDA in the evaluation model. The focus will be on the scores of the single criteria by changing their weights (from “0” - minimum to “1” - maximum) individually. Conclusions are deducted from the changes made on the final score. In the next section the changes made on the scores of one level up of the criteria examined will be considered.

5.5.1 Cell Phone

In this section the focus is on the effects the changes of the weights had on the score of the Cell Phone. In Figure 5-32 one can see the comparison of the different criteria with their minimum, average and maximums displayed.

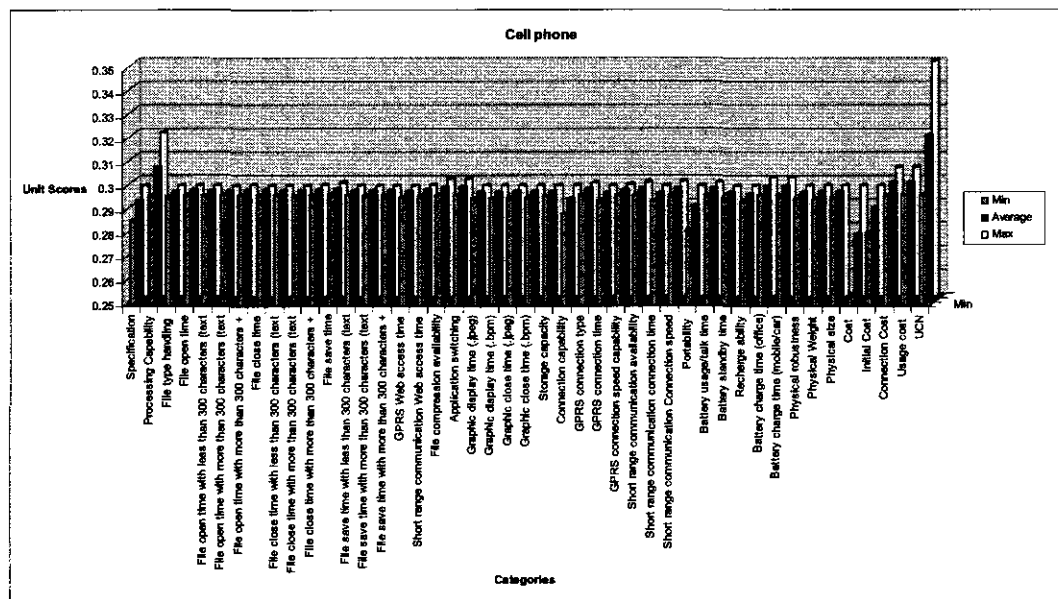


Figure 5-32: Weight effect individual criteria via minimum, average and maximum values (final score) for the Cell

One can detect the criteria that are sensitive to changes and carry a big weight in the evaluation model by comparing the minimum and maximum of each criterion. As one



would expect the higher the level of the criteria the bigger the impact on the evaluation model.

From the level-1 criteria (Specification, Cost and Usability/UCN) the Usability and Cost show the biggest change and thus the correct selection of the weights for criteria is important. The Specification also plays a big role and should be selected carefully.

From the level-2 criteria the only criteria that seem to have a big impact directly on the final score are: Specification-Processing Capability, Specification-Connection Capability, Specification-Portability and Cost-Initial Cost.

5.5.2 PDA

In this section the focus will be on the effects the changes of the weights have on the score of the PDA. In Figure 5-33 one can see the comparison of the different criteria with their minimum, average and maximums displayed.

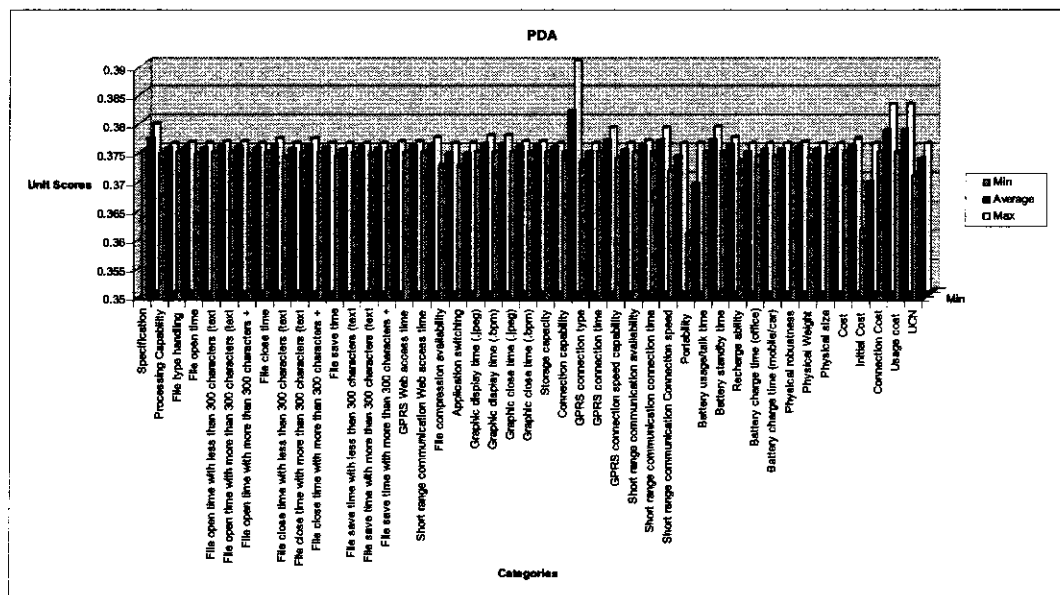


Figure 5-33: Weight effect individual criteria via minimum, average and maximum values (final score) for the PDA

From the level-1 criteria (Specification, Cost and Usability/UCN) the changes from minima to maxima seem to be in the same order, thus making all the level-1 criteria equally important.

From the level-2 criteria the only criteria that seem to have a big impact directly to the final score are: Specification-Connection Capability, Specification-Portability and Cost-Initial Cost. Thus the correct selections of the weights for these criterions are important.

5.5.3 Laptop

In this section the focus will be on the effects the changes of the weights have on the score of the Laptop. In Figure 5-34 one can see the comparison of the different criteria with their minimum, average and maximums displayed.

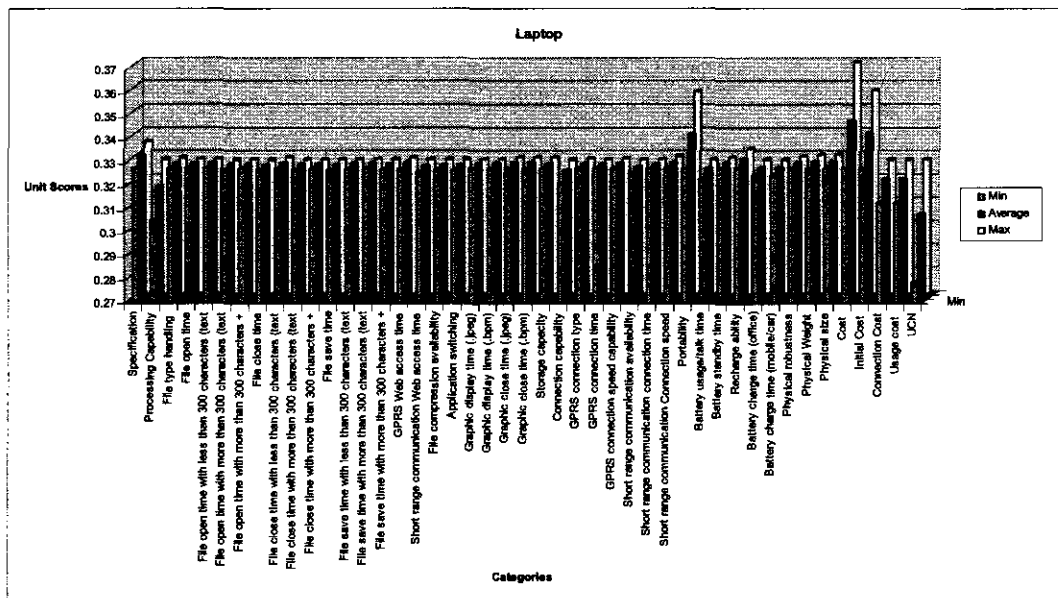


Figure 5-34: Weight effect individual criteria via minimum, average and maximum values (final score) for the Laptop



From the level-1 criteria (Specification, Cost and Usability/UCN) the Usability and Cost shows the biggest change, and thus the correct selection of the weights for these criteria is important. The Specification also plays a big role and should be selected carefully.

From the level-2 criteria the only criteria that seem to have a impact directly on the final score are: Specification-Processing Capability, Specification-Portability, Cost-Initial Cost, Cost-Connection Cost and Cost-Usage Cost. Therefore the correct selection of the weights for these criteria are important.

5.5.4 Average Scores of field units

In this section the focus will be on the average scores that were achieved by changing the weights of the individual criteria consecutively.

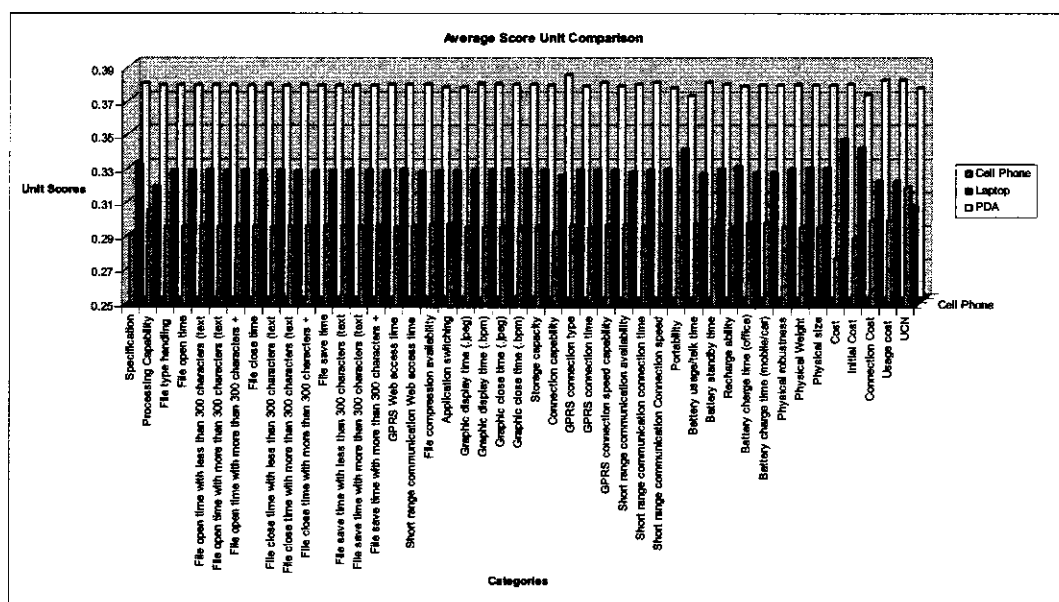


Figure 5-35: Average scores of the different field units when changing individual weights

In Figure 5-35 one can find the average scores achieved by the by the field units when changing their criteria weights one at a time from “0” to “1” while keeping the weights of the other criteria “1”. This is done to enable one to observe which field unit scores the

best on average when one is not sure of the weights that should be applied to the criteria. When studying Figure 5-35, one can conclude that the PDA is by far the best option for the Telkom case study.

5.5.5 Changes in Scores

In the following section the focus will be on the criteria in which big changes in the final scores were achieved by changing the weights of the individual criteria consecutively. In Figure 5-36 one can observe the magnitude of the changes that occurred when changing the weights.

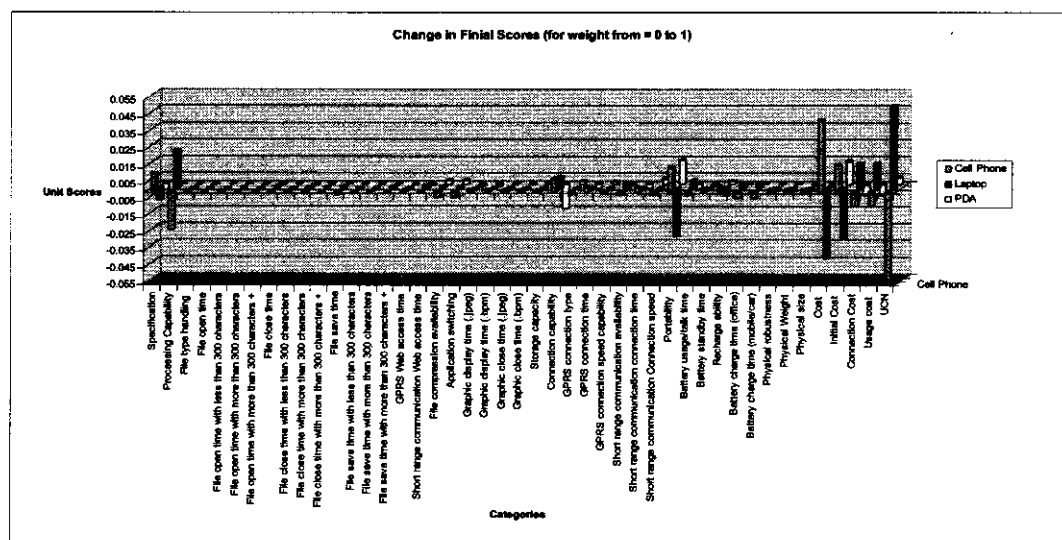


Figure 5-36: Change in final score for changes of weights of individual criteria

Specification

When studying Figure 5-36 one can observe that there are criteria that cause a larger change in final score than the other criteria with weight changes. These criteria (Specification, Processing Capability, Connection Capability, Portability, Cost, Initial Cost, Connection Cost, Usage cost, Usability) are the criteria that show the biggest sensitivity to changes in the weights. A more in depth discussion on change in final score (while changing the weights of the individual criteria consecutively) can be found in Appendix F.



5.5.6 Conclusion MCDA Single Criteria Sensitivity (on final score)

In the section above the focus was on the effects the changes of the weights had on the score of the field units in terms of the changes it makes in the final scores. In Figure 5-36 one can see the comparison of the different criteria with their changes displayed. It is noticed that the criteria that are sensitive to changes and carry a big weight in the evaluation model had higher values in Figure 5-36. Therefore by comparing the minimum and maximum of each criterion one can conclude that the higher the level of the criteria the bigger the impact the unit has on the evaluation model.

An in depth discussion on “change in final score”, while changing the weights of the individual criteria consecutively can be found in Appendix F.

By focusing on Figure F-1 to Figure F-9 one observed that the PDA seems to be the most stable field unit for our case study. This is concluded from the fact that in most of the figures studied, the PDA's score changes the least, making it the least sensitive unit to changes of criteria weights for this type of sensitivity analysis.

5.6 MCDA Single Criteria Sensitivity (on “one level up” score)

In the following section the attention will be on the sensitivity of the MCDA in the evaluation model. The focus will be on the single criteria by changing their weights (from “0” - minimum to “1” - maximum) individually and considering changes it makes on the scores of one level up of the criteria examined).

5.6.1 Cell Phone

In this section the focusing will be on the effects the changes of the weights have on the score of the Cell Phone. In Figure 5-37 one can see the comparison of the different criteria with their minimum, average and maximums displayed.

One can detect the criteria that are sensitive to changes and carry a big weight in the evaluation model by comparing the minimum and maximum of each criterion. As one



would expect the higher the level criteria the bigger the impact the unit has on the evaluation model.

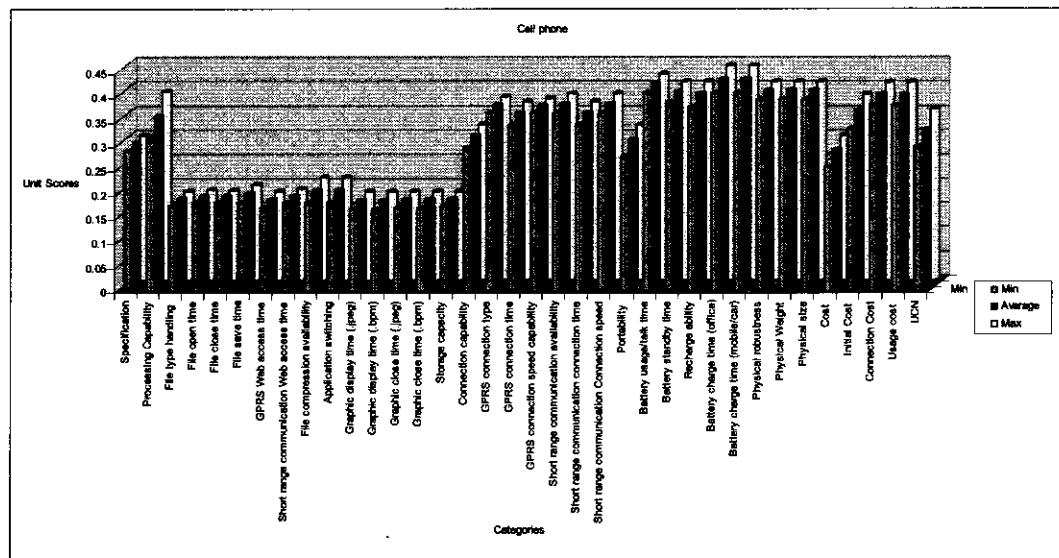


Figure 5-37: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the Cell

From the level-1 criteria (Specification, Cost and Usability/UCN), the Usability and Cost show the biggest change and thus the careful selection of the weights for these criteria is important. The Specification changes are also notable but are relatively small in comparison to the changes of the other criteria.

From the level-2 criteria the only criteria that seem to have an accountable impact directly to their level-1 criteria are: Specification-Processing Capability, Specification-Portability and Cost-Initial Cost.

From the level-3 criteria the only criteria that seem to have an accountable impact directly to their level-2 criteria are: Processing Capability-Application Switching, and Processing Capability-Compression Capability.



5.6.2 PDA

In this section the focus will be on the effects the changes of the weights have on the score of the PDA. In Figure 5-38 one can see the comparison of the different criteria with their minimum, average and maximums displayed.

One can detect the criteria that are sensitive to changes and carry a big weight in the evaluation model by comparing the minimum and maximum of each criterion. As one would expect the higher the level of the criteria the bigger the impact the unit has on the evaluation model.

From the level-1 criteria (Specification, Cost and Usability/UCN), the changes from minimums to maximums seem to be in the same order (almost no change compared the changes in the other criteria), thus making all the level-1 criterions equally insensitive to changes.

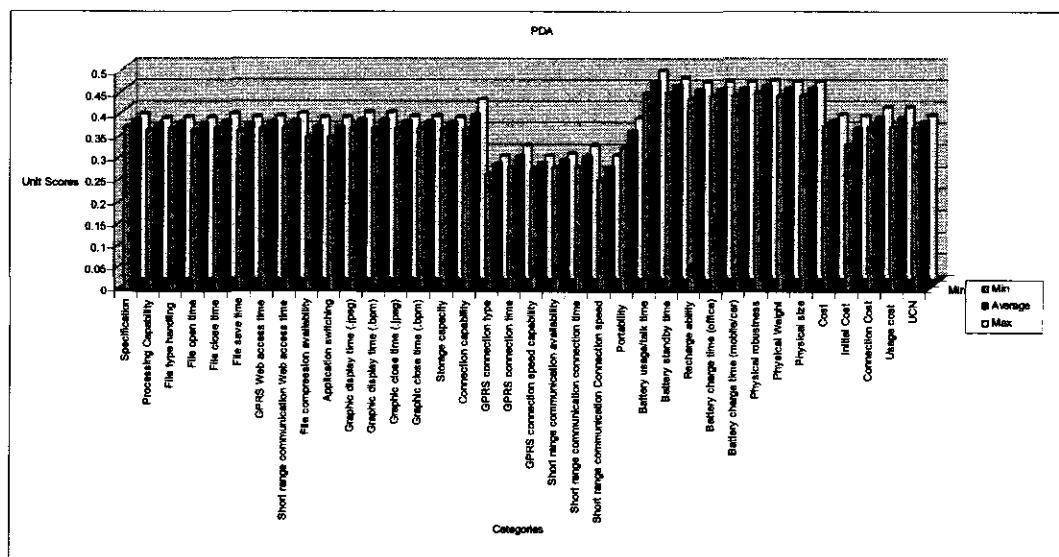


Figure 5-38: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the PDA

From the level-2 criteria the only criteria that seem to have a big impact directly on the score of the “one level up criterion” are: Specification-Connection Capability, Specification-Portability and Cost-Initial Cost. Therefore the correct selection of the weights for these criteria is important.

From the level-3 criteria the only criteria that seem to have a accountable impact directly to there level-2 criterions are: Connection Capability, Short range communication Connection speed, Portability-Battery usage/talk time.

5.6.3 Laptop

In this section the focus will be on the effects the changes of the weights have on the score of the Laptop. In Figure 5-39 one can see the comparison of the different criteria with their minimum, average and maximum displayed.

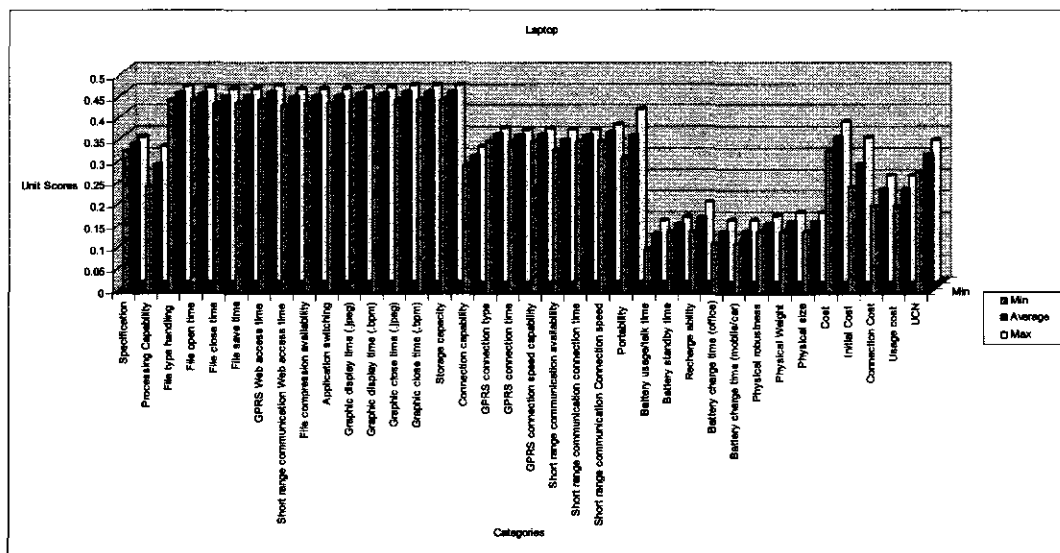


Figure 5-39: Weight effect individual criteria via minimum, average and maximum values (one level up score) for the Laptop



One can detect the criteria that are sensitive to changes and carry a big weight in the evaluation model by comparing the minimum and maximum of each criterion. As one would expect the higher the level of the criteria the bigger the impact the unit has on the evaluation model.

From the level-1 criteria (Specification, Cost and Usability/UCN), the Usability and Cost shows the biggest change, and therefore the correct selection of the weights for these criteria is important. The Specification does not seem to play a big role, thus selection of weights for this criterion is not very sensitive.

From the level-2 criteria the only criteria that seem to have an impact directly on the score of the "one level up criterion" are: Specification-Processing Capability, Specification-Portability, Cost-Initial Cost, Cost-Connection Cost and Cost-Usage Cost. Thus the correct selections of the weights for these criteria are important.

From the level-3 criteria the only criteria that seem to have an accountable impact directly to their level-2 criteria are: Portability-Battery usage/talk time, Portability-Recharge ability, Portability-Battery charge time.

5.6.4 Average Scores of field units

In this section the focus will be on the average scores that were achieved by changing the weights of the individual criteria consecutively.

In Figure 5-40 one can find the average scores achieved by the field units when changing their criteria weights one at a time from "0" to "1" while keeping the weights of the other criteria at "1". This is done to enable one to observe which field unit scores the best on average when one is not sure of the weights that should be applied to the criteria.



the previous section (the criteria that had a big affect on the final score).

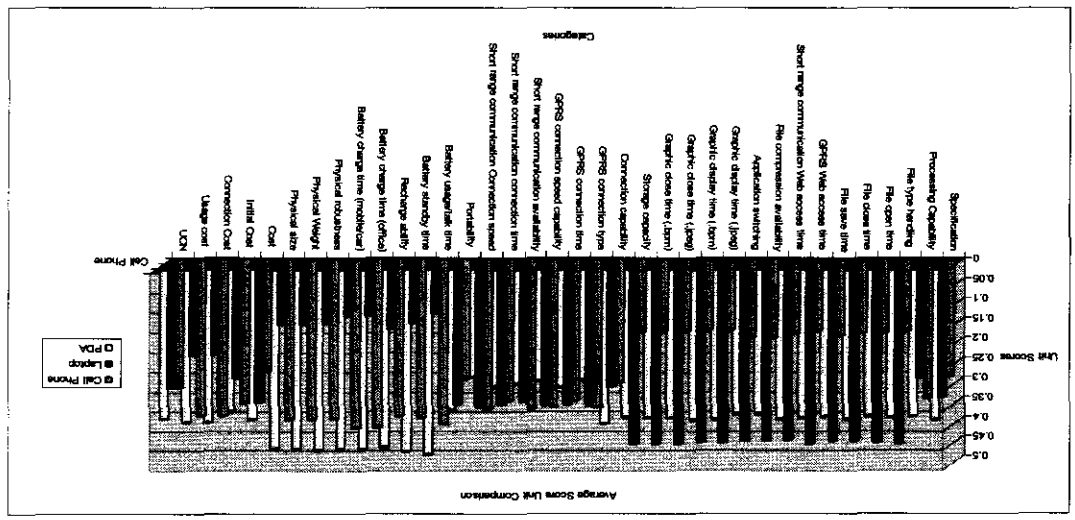
an affect on their "one level up" criteria are much more than those that were discussed in occurred. When studying this figure one can observe that the number of criteria that have criteria consecutively. In Figure 5-41 one can observe the magnitudes of the changes that in the "one level up" scores that were achieved by changing the weights of the individual In the following section the focus will be on the criteria in which there were big changes

5.6.5 Changes in Scores

Laptop is at least half the magnitude.

for the "Cost" criteria, the Cell Phone and PDA is again in the same order while the seem to be in the same order while the Laptop is at least a third of the magnitude. lastly followed shortly by the Cell Phone and lastly by the Laptop (the PDA and Cell Phone The PDA seems to be the strongest contestant in the "Portability Capability" criteria in the "Connection Capability" criteria followed by the PDA which is not far behind. would expect). The Laptop and Cell Phone seems to be equal for the strongest contestant Capability" criteria followed by the PDA and then the Cell Phone (This is what one unique strengths. The Laptop seems to be the strongest contestant in the "Process When studying Figure 5-40 one can conclude that the each of the field units has its own

Figure 5-40: Average scores of the different field units when changing individual weights



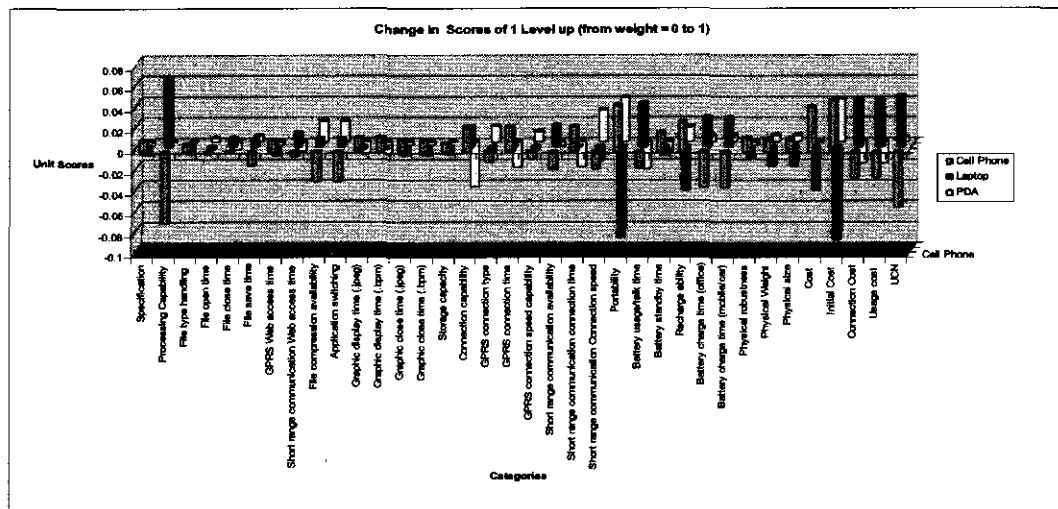


Figure 5-41: Change in “one level up” scores for changes of weights of individual criteria

These criteria (Processing Capability, File compression availability, Application switching, Connection capability, GPRS connection time, Short range communication availability, Short range communication connection time, Short range communication Connection speed, Portability, Recharge ability, Cost, Connection Cost, Usage cost, and Usability) are the criteria that show the biggest sensitivity to changes in the weights. A more in depth discussion on change in “one level up” score (while changing the weights of the individual criteria consecutively) can be found in Appendix F.

5.6.6 Conclusion of MCDA Single Criteria Sensitivity (on one level up score)

In the section above, the focus was on the effects the changes of the weights had on the score of the field units in terms of the changes made in the “one level up” scores (“one level up” – meaning that if the weights of a level-2 criteria changes, a look at what changes in score it causes in its level-1 criteria) are taken. In Figure 5-41 one can see the comparison of the different criteria with their changes displayed. It was detected that the criteria that are sensitive for changes and carry a big weight in the evaluation model had higher values in Figure 5-41. In this section it is observed that the number of criteria that



were affected on their “one level up” criteria much more than those that were discussed in the previous section (the criteria that had a big affect on the final score).

By focusing on Figure F-10 to Figure F-24 it is observed that the PDA seems to be the most stable field unit for the case study. But in contradiction with the previous sensitivity analyses, the PDA does show some grade of sensitivity. Therefore the PDA is less sensitive to changes in the weights than the Cell Phone and Laptop, but should still be considered as sensitive in this sensitivity analyses

5.7 Conclusion

In the above section the focus was on the sensitivity analysis of the evaluation module. The interaction of the all the criteria were tested at all the criteria levels. The conclusion of the two main steps that were conducted is:

- **Effect on final score:** In Figure 5-36 one can see the comparison of the different criteria with their changes displayed. By focusing on Figure F-1 to Figure F-9 one observes that the PDA seems to be the most stable field unit for this case study. This is concluded from the fact that in most of the figures studied, the PDA's score changes the least, making it the least sensitive unit to changes of criteria weights for this type of sensitivity analyses.
- **Effect on “one level up” score:** In Figure 5-41 one can see the comparison of the different criteria with their changes displayed. By focusing on Figure F-10 to Figure F-24 one can observe that the PDA seems to be the most stable field unit for the case study. This is concluded from the fact that in most of the figures studied the PDA's score changes the least, making it the least sensitive unit to the changes of criteria weights for these types of sensitivity analyses.

After studying the results of the sensitivity analysis one can deduct with certainty that the PDA is the least sensitive for the Telkom case study and that the evaluation model is relatively stable and consists of criteria that are certain and uncertain.



CHAPTER SIX

6 Conclusion

In this chapter of the dissertation a summary of the research can be found, as well as the conclusions made from the research. The two main focus areas of the research that are discussed are:

- The creation of an evaluation method (MCDA with UCN incorporated) that is capable to cope with certain and uncertain criteria.
- The application of the adapted MCDA evaluation method on Telkom's upgraded WebForce dispatching system. The evaluation is focused specifically on the functionality of the field units that must be used in the new system.



6.1 Background Summary

During the first chapter the focus was placed on the basic background (conversion from the old WebForce dispatch system to the new WebForce dispatch system) that led to the identification of the project, the objectives and methodology of the project. The benefits and the value of the research were clarified. In conclusion a brief review was presented concerning previous related projects. From these references, the evaluation model and techniques were chosen to be used in the evaluation of the case study.

6.2 GPRS Survey Summary

In the second chapter the focus was placed on more advanced concepts of this research. It is a more comprehensive discussion on the topics that were mentioned in chapter 1. The survey covered aspects of the GPRS architecture to enable one to understand GPRS data transfer. The main purpose of the chapter was to inform the reader of the type of environment the field units that were evaluated would be working and what were their functional requirements were.

6.3 MCDA Survey Summary

In Chapter 3 the focus was on advanced concepts of evaluation processes. In this chapter a literature survey was conducted that covered the aspects of evaluation models and techniques that were needed to complete and understand the evaluation process. The survey covered MCDA evaluation methods and Weighted Sum techniques that are used in this case study to evaluate the 3 different types of field unit classes.

In this section the MCDA method was discussed and became evident that there are limitations to this method. The three assumptions that standard MCDA makes are:

- That the criteria are well defined (hence for a given action a it is obvious how one can compute $g(a)$ for a given criteria g).



- The relevant criteria are certain (and hence for a given action a and criteria g , the value $g(a)$ is deterministic rather than stochastic).
- That the relevant criteria are independent of each other.

These can be seen as the limitations of MCDA because they restrict the evaluation to problems that only have certain criteria. The limitations needed to be overcome to enable the MCDA method to be applied to decision making problems where the criteria are uncertain or the criteria does not a specific value.

6.4 Evaluation Process Summary

In real life decision making, the criteria used for the evaluation is not always certain. This posed to be a problem when using standard MCDA (as in Chapter 3), because it assumes that all relevant criteria of a evaluation problem are certain.

This problem was solved by adapting the standard MCDA evaluation method. The adaptation was done using an UCN network to calculate a value for each uncertain criterion for a given action, thus leaving only certain criteria for given actions. UCNs help to make predictions about uncertain factors like the functionality of a proposed system.

The value of the evaluation method can be summarised as follows: An evaluation model is produced for the use of the evaluation of field units for the new proposed "*Field force Automation*" project. Methods and techniques are presented that will make the evaluation process for future work easier. This process will enable one to make a recommendation to Telkom on the class of field unit that will best suit the task .



6.5 Sensitivity Analysis Conclusion

The focus of Chapter 5 was on the sensitivity analysis of the evaluation model that was created during the project. The interaction of all the criteria were tested at all the criteria levels. The analyses were conducted on both the MCDA and the UCN evaluation models.

MCDA: In this analysis the focus was on the sensitivity of the MCDA. In this section two main types of test were conducted:

- **Effect on final score:** In the section the attention was on the effects the changes of the weights had on the score of the field units in terms of the changes made on the final scores. In Figure 5-36 one can see the comparison of the different criteria with their changes displayed. The criteria that are sensitive to changes and carry a big weight in the evaluation model were noted. By comparing the minimum, maximum and average of all the criteria identified the most sensitive criteria were: Specification, Processing Capability, Connection Capability, Portability, Cost, Initial Cost, Connection Cost, Usage cost and Usability

By focusing on Figure F-1 to Figure F-9 it was observed that the PDA seemed to be the most stable field unit for this case study. This is concluded from the fact that in most of the figures studied, the PDA's score changes the least, making it the least sensitive unit to changes of criteria weights for this type of sensitivity analysis.

- **Effect on "one level up" score:** In this section the focus was on the effect the changes of the weights had on the score of the field units in terms of the changes made in the "one level up" scores ("one level up" – meaning that if the weights of a level-2 criteria changes, the changes in score it causes in its level-1 criteria) are noted. In Figure 5-41 one can see the comparison of the different criteria with their changes displayed. It was noted that the criteria that are sensitive to changes and carry a big weight in the evaluation model had higher values in Figure 5-41.



In this section it is observed that the number of criteria that were affected on their "one level up" criteria are more numerous than those that were discussed in the previous section (the criteria that had a big affect on the final score).

By focusing on Figure F-10 to Figure F-24 it's observed that the PDA seems to be the most stable field unit for the case study. In contradiction with the previous sensitivity analyses, the PDA does show some grade of sensitivity. Thus the PDA is less sensitive to changes in the weights than the Cell Phone and Laptop ,but should still be considered as sensitive in these sensitivity analyses.

By studying the deviations in the sensitivity analyses, the PDA seems to be the most stable (small deviations in score due to changes in the weights) field unit for the case study. This is concluded from the fact that the PDA's score changes the least in most of the figures studied, making it the least sensitive unit to changes of criteria weights for this type of sensitivity analyses.

UCN: Viewing the basic forms of the 3D plots (that can be found in Chapter 6), it can be observed that the Laptop is not really affected by the changes that were made to the criteria's weights. Thus the Laptop is not sensitive to changes in aspects of the Usability (UCN) criteria due to the level of specification, which is above the required specification. Looking at the maximum and minimum scores for the field units, the Laptop is the best option for the Usability criteria followed shortly by the PDA, whereas the Cell Phone dropped out completely when considering the Telkom case study requirements.

After studying the results of the UCN sensitivity analysis it can be concluded with certainty that the PDA is the best option for the case study and that the evaluation model is relatively stable in evaluation model which consists of certain and uncertain criteria .

Summary: After studying the results of all of the sensitivity analyses, one can conclude with certainty that the PDA is the least sensitive for the Telkom case study and that the



evaluation model is (relatively) stable in an evaluation model that consists of criteria that are certain and uncertain.

6.6 Future work

With the current research in place, as presented in this document, one can now design/program a fully automated evaluation software program that can be implemented by any evaluation method that consists of certain and uncertain criteria. One can use the semi-automated Microsoft Excel work sheet (that was used for the evaluation of the case study) as a guideline for the creation of the fully automated program.

6.7 “In a Nutshell”

The value of the project can be divided into two aspects:

- The creation of an evaluation method (MCDA with UCN incorporated) that is capable to cope with certain and uncertain criteria.
- The task dispatching automation upgrade of Telkom's WebForce department was used as a case study for the application of the adapted MCDA evaluation model. It was concluded that the PDA was the best option for the Telkom case study.



REFERENCES

- [1] C. Chiba, R. Volkwyn, "Field Force Automation Project", Telkom-Enhanced Services, 2003.
- [2] B. Ghribi, L. Logrippo, "Understanding GPRS: the GSM packet radio service", Telecommunications Software Engineering Research Group, School of Information Technology and Engineering, University of Ottawa, 2000.
- [3] "Guidelines Tender Evaluation Using Weighted Criteria", Department Of Treasury And Finance, September 1999
- [4] I. Stamelos, I. Vlahavas, I. Refanidis, A. Tsoukia, "Knowledge based evaluation of software systems: a case study", a Department of Informatics, Aristotle University of Thessaloniki, September 1999.
- [5] P. Baumgartner, "Methods and Practice of Software Evaluation. The Case of the European Academic Software Award, Institute for Interdisciplinary Research and Further Education (IFF), University of Klagenfurt, Austria, 1997
- [6] C. Friedman, J. Wyatt, "Evaluation Methods in Medical Informatics", Springer, New York, 1997, pp. 20–21.
- [7] J. P. Henderson, M. Smith and H. Varela-Alvarez, "An Examination of Four User-based Software Evaluation Methods, Interacting with Computers", Volume 7, Issue 4, Pages 412-432, Dec 1995.
- [8] G. Gediga, K. Hamborg, I. Düntsch, "Evaluation of Software Systems", School of Information and Software Engineering, University of Ulster, 2000.
- [9] S. Riihiäho, "Experiences with Usability Evaluation Methods", Department of Computer Science and Engineering, Helsinki University of Technology, May 8, 2000.
- [10] T. Hubscher-Younger, R. Hubscher, R. Chapman, "An Experimental Comparison of Two Popular PDA User Interfaces", Department of Computer Science and Software Engineering, Auburn University, September, 2001.
- [11] Brahim Ghribi, Luigi Logrippo, "Understanding GPRS: the GSM packet radio service", Telecommunications Software Engineering Research Group, School of Information Technology and Engineering, University of Ottawa, 2000



-
- [12] C. Lindemann, A. Theummler, "Performance analysis of the general packet radio service", Department of Computer Science, University of Dortmund, 28 May 2002.
- [13] D. Lal, N. Gupta, N. Auluck and S. Doumit, "Gprs -- General Packet Radio Service", Department Of Electrical and Computer Engineering and Computer Science, University of Cincinnati, 2003
- [14] C. Lindemann and A. Thümmel, "Performance Analysis of the General Packet Radio Service", Department of Computer Science, University of Dortmund, 2001.
- [15] "Third Generation Wireless Systems : UMTS and IMT2000", Lucent Technologies, Nov 1997
- [16] "Bluetooth and Pervasive Computing", <http://www.earthskater.com/library/bluetooth.htm> , Dec 2001
- [17] "Understanding Wi-Fi", <http://www.hp.com/sbso/wireless/images/understandingWiFi.pdf> , Jan 2002
- [18] A. Vaha-sipla, "Ciphering in GPRS and UMTS", Telecommunications Laboratory, Tampere University of technology, 2000.
- [19] I. Stamelos, I. Vlahavas, I. Refanidis, A. Tsoukia, "Knowledge based evaluation of software systems: a case study", Department of Informatics, Aristotle University of Thessaloniki, Sep 1999
- [20] P E Jacquet-Langreze, Y Siskos, "MCDA methodologies for classifying and sorting", Department of Engineering and Management, Technical University of Crete, Greece, 2002.
- [21] P Vinke, "Multicriteria Decision Aid", Wiley, New York, 1992.
- [22] F S Roberts, "Measurement Theory with Applications to decision making, Utility, and Social Science", Addison-Wesley, Reading, 1979.



Appendix A : Acronyms

AH	Authentication Header
AuC	Authentication Centre
BSC	Base Station Controllers
BSS	Base Station Subsystem
BTS	Base Transceiver Stations
CDMA	Code Division Multiple Access
CKSN	Chipper key sequence
CS1	Coding Scheme 1
CS2	Coding Scheme 2
CS3	Coding Scheme 3
CS4	Coding Scheme 4
FCS	Frame Check Sequence
EDGE	Enhanced Data Rates for GSM Evolution
EIR	Equipment Identity Register
ESP	Encapsulating Security Payload
FDD	Functional Definition Document
FDMA	Frequency Division Multiple Access
GGSN	Gateway GPRS Support Node
GMM/SM GPRS	Mobility Management and Session Management
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GMSK	Gaussian minimum-shift keying
GSN	GPRS Support Node
GTP	GPRS TUNNELING PROTOCOL
HLR	Home Location Register
HSCSD	High-Speed Circuit-Switched Data
IETF	Internet Engineering Task Force
IKE	Internet Key Exchange
IP	Internet Protocol
IPSec	Internet Protocol security



Kc	Encryption key
Ki	Encryption key
LLC	Logical Link Control
NWS	Numerical Weight and Sum
NSS	Network Switching Subsystem
MCDA	Multiple-Criteria Decision Aid
MT	Mobile Terminal, Mobile Terminated
MSC	Mobile Switching Centre
MS	Mobile Station
NSS	Network Switching Subsystem
PDA	Personal Digital Assistant
PCU	Packet Control Unit
PIN	Personal Identification Number
PDN	Packet Data Network
PDP	Packet Data Protocol
PDU	Protocol Data Unit, Packet Data Units
PLMN	Public Land Mobile Network
QWS	Qualitative Weight and Sum
RF	Radio Frequency
RLC	Radio Link Control
SAP	Service Access Point
SG	Secure Gateway
SGSN	Serving GPRS Support Node
SMS	Short Message Service
SSL	Secure Socket Layer
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TLLI	Temporary Logical Link Identity
UMTS	Universal Mobile Telecommunications Systems
VLR	Visitor Location Register
VPN	Virtual Private Network
WAP	Wireless Application Protocol
WCDMA	Wideband CDMA



WS	Weighted Sum
WTLS	Transport Layer Security
3GPP	Third Generation Partnership Project



Appendix B : Step 3 – Evaluation Attribute Tree

The functionality is divided into three main attributes (specification, usability, cost). Each one of these attributes has a compound nature and must be decomposed until all the attributes cannot be decomposed further.

Specification (d1)

- Processing Capability (d11)
 - File type handling (d11.1)
 - File open time (d11.2)
 - File open time with less than 300 characters (text only) (d11.2.1)
 - File open time with more than 300 characters (text only) (d11.2.2)
 - File open time with more than 300 characters + picture (d11.2.3)
 - File close time (d11.3)
 - File close time with less than 300 characters (text only) (d11.2.1)
 - File close time with more than 300 characters (text only) (d11.2.2)
 - File close time with more than 300 characters + picture (d11.2.3)
 - File save time (d11.4)
 - File save time with less than 300 characters (text only) (d11.2.1)
 - File save time with more than 300 characters (text only) (d11.2.2)
 - File save time with more than 300 characters + picture (d11.2.3)
 - GPRS Web access time (d11.5)
 - Short range communication Web access time (d11.6)
 - File compression availability (d11.7)
 - Application switching (d11.8)
 - Graphic display time (.jpeg) (d11.9)
 - Graphic display time (.bmp) (d11.10)
 - Graphic close time (.jpeg) (d11.11)
 - Graphic close time (.bmp) (d11.12)
 - Storage capacity (d11.13)
- Connection Capability (d12)
 - GPRS connection type (d12.1)
 - GPRS connection time (d12.2)
 - GPRS connection speed (d12.3)
 - Short range communication availability (d12.4)
 - Short range communication connection time (d12.5)
 - Short range communication Connection speed (d12.6)
- Portability (d13)
 - Battery usage/talk time (d13.1)



- Battery standby time (d13.2)
- Recharge ability (d13.3)
- Battery charge time (office) (d13.4)
- Battery charge time (mobile/car) (d13.5)
- Physical robustness (d13.6)
- Physical weight (d13.7)
- Physical size (d13.8)

Cost (d2)

- Initial Cost (d21)
 - Unit purchase cost (d21.1)
 - User training cost (d21.2.)
 - Unit Operating System cost (d21.3)
 - GPRS software cost (d21.4)
 - Short range Communication software cost (d21.5)
- Connection Cost (d22)
 - Initial GPRS connection cost (d22.1)
 - Initial Short range communication connection cost (d22.2)
- Usage Cost (d23)
 - GPRS monthly average usage cost (d23.1)
 - Short range average usage cost (d23.2)
 - GPRS monthly average subscription (d23.3)
 - Short range monthly average subscription (d23.4)

Usability (d3): UCN – one is unable to divide the usability into certain criteria (which is an assumption that MCDA makes)



Appendix C : Step 4, 5 – Summary

C.1 Process Capability

Table C-1: MCDA steps 4, 5 - Process Capability

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d11					
d11.1	Md11.1	Nv	Ed11.1	Text only (characters < 300)	0.1
				Text only (characters ≥ 300)	0.2
				Text + picture (separate: text + jpeg, bmp)	0.3
				Text + picture (single file: .doc, .pdf)	0.4
d11.2					
d11.2.1	Md11.2.1	Av	Ed11.2.1	time ≤ 0.75 s	0.5
				0.8 s ≤ time ≤ 2 s	0.35
				2 s ≤ time ≤ 2.4 s	0.15
				2.4 s ≤ time	0
d11.2.2	Md11.2.1	Av	Ed11.2.2	time ≤ 0.8 s	0.5
				0.8 s ≤ time ≤ 1 s	0.35
				1 s ≤ time ≤ 2.95 s	0.15
				2.95 s ≤ time	0
d11.2.3	Md11.2.1	Av	Ed11.2.3	time ≤ 3 s	0.5
				3 s ≤ time ≤ 4.25 s	0.35
				4.25 s ≤ time ≤ 4.4 s	0.15
				4.4 s ≤ time	0
d11.3					
d11.3.1	Md11.3.1	Av	Ed11.3.1	time ≤ 0.4 s	0.5
				0.4 s ≤ time ≤ 2.2 s	0.35
				2.2 s ≤ time ≤ 3.5 s	0.15
				3.5 s ≤ time	0
d11.3.2	Md11.3.2	Av	Ed11.3.2	time ≤ 0.5 s	0.5
				0.5 s ≤ time ≤ 3.35 s	0.35
				3.35 s ≤ time ≤ 5.4 s	0.15
				5.4 s ≤ time	0
d11.3.3	Md11.3.3	Av	Ed11.3.3	time ≤ 0.5 s	0.5
				0.5 s ≤ time ≤ 0.625 s	0.35
				0.625 s ≤ time ≤ 1.8 s	0.15
				1.8 s ≤ time	0



Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d11.4					
d11.4.1	Md11.4.1	Av	Ed11.4.1	time ≤ 0.75 s	0.5
				0.75 s $\leq$ time ≤ 1.7 s	0.35
				1.7 s $\leq$ time ≤ 6.65 s	0.15
				6.65 s $\leq$ time	0
d11.4.2	Md11.4.1	Av	Ed11.4.2	time ≤ 2 s	0.5
				2 s $\leq$ time ≤ 2.3 s	0.35
				2.3 s $\leq$ time ≤ 9.7 s	0.15
				9.7 s $\leq$ time	0
d11.4.3	Md11.4.3	Av	Ed11.4.3	time ≤ 0.5 s	0.5
				0.5 s $\leq$ time ≤ 0.625 s	0.35
				0.625 s $\leq$ time ≤ 1.85 s	0.15
				1.85 s $\leq$ time	0
d11.5	Md11.5	Av	Ed11.5	time ≤ 12 s	0.5
				12 s $\leq$ time ≤ 22 s	0.35
				22 s $\leq$ time ≤ 34.5 s	0.15
				34.5 s $\leq$ time	0
d11.6	Md11.6	Av	Ed11.6	time ≤ 0.4 s	0.5
				4 s $\leq$ time ≤ 0.6 s	0.35
				0.6 s $\leq$ time ≤ 5 s	0.15
				5 s $\leq$ time	0
d11.7	Md11.7	Nv	Ed11.7	yes	1
				no	0
d11.8	Md11.8	Nv	Ed11.8	yes	1
				no	0
d11.9	Md11.9	Nv	Ed11.9	time ≤ 0.5 s	0.5
				0.5 s $\leq$ time ≤ 1.625 s	0.35
				1.625 s $\leq$ time ≤ 3.4 s	0.15
				3.4 s $\leq$ time	0
d11.10	Md11.10	Av	Ed11.10	time ≤ 0.4 s	0.5
				0.4 s $\leq$ time ≤ 1.7 s	0.35
				1.7 s $\leq$ time ≤ 6.6 s	0.15
				6.6 s $\leq$ time	0
d11.11	Md11.11	Av	Ed11.11	time ≤ 1.375 s	0.5
				1.375 s $\leq$ time ≤ 1.6 s	0.35
				1.6 s $\leq$ time ≤ 1.75 s	0.15
				1.75 s $\leq$ time	0
d11.12	Md11.12	Av	Ed11.12	time ≤ 0.5 s	0.5
				0.5 s $\leq$ time ≤ 1.575 s	0.35
				1.575 s $\leq$ time ≤ 1.8 s	0.15
				1.8 s $\leq$ time	0



Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d11.13	Md11.13	Av	Ed11.13	text messages > 1000	0.5
				150 < text messages < 1000	0.35
				text messages < 150	0.15

C.2 Connection Capability

Application: looking at the *Connection Capability (d12)* which is a sub-attribute of the *Specification* attribute, the following can be defined:

Table C-2: MCDA steps 4, 5 - Connection Capability

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d12					
d12.1	Md12.1	Nv	Ed12.1	Down link slots < 2	0
				2 ≤ Down link slots < 3	0.15
				3 ≤ Down link slots < 4	0.3
				4 ≤ Down link slots	0.5
d12.2	Md12.2	Av	Ed12.2	time ≤ 6 s	0.5
				6 s ≤ time ≤ 16.5 s	0.35
				16.5 s ≤ time ≤ 18 s	0.15
				18 s ≤ time	0
d12.3	Md12.3	Av	Ed12.3	Data rate ≤ 27.5 kbps	0
				27.5 kbps ≤ Data rate ≤ 38 kbps	0.15
				38 kbps ≤ Data rate ≤ 40 kbps	0.35
				40 kbps ≤ Data rate	0.5
d12.4	Md12.4	Av	Ed12.4	Data cable & Wi-Fi	0.4
				Data cable & Bluetooth	0.3
				Data cable & iRDA	0.2
				Data cable only	0.1
d12.5	Md12.5	Av	Ed12.5	time ≤ 3 s	0.5
				3 s ≤ time ≤ 5.3 s	0.35
				5.3 s ≤ time ≤ 13.5 s	0.15
				13.5 s ≤ time	0
d12.6	Md12.6	Av	Ed12.6	Data rate ≤ 600 kbps	0
				600 kbps ≤ Data rate ≤ 1200 kbps	0.15
				1200 kbps ≤ Data rate ≤ 2000 kbps	0.35
				2000 kbps ≤ Data rate	0.5



C.3 Portability

Application: looking at the *Portability (d13)* which is a sub-attribute of the *Specification* attribute, the following can be defined:

Table C-3: MCDA steps 4, 5 - Portability

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d13					
d13.1	Md13.1	Av	Ed13.1	time $\leq$ 112.5 min	0
				112.5 min $\leq$ time $\leq$ 137.5 min	0.15
				137.5 min $\leq$ time $\leq$ 150 min	0.35
				150 min $\leq$ time	0.5
d13.2	Md13.2	Av	Ed13.2	time $\leq$ 62.5 hrs	0
				62.5 hrs $\leq$ time $\leq$ 164.6 hrs	0.15
				164.6 hrs $\leq$ time $\leq$ 500 hrs	0.35
				500 hrs $\leq$ time	0.5
d13.3	Md13.3	Nv	Ed13.3	yes	1
				no	0
d13.4	Md13.4	Av	Ed13.4	time $\leq$ 150 min	0.5
				150 min $\leq$ time $\leq$ 160 min	0.35
				160 min $\leq$ time $\leq$ 265 min	0.15
				265 min $\leq$ time	0
d13.5	Md13.5	Av	Ed13.5	time $\leq$ 150 min	0.5
				150 min $\leq$ time $\leq$ 160 min	0.35
				160 min $\leq$ time $\leq$ 265 min	0.15
				265 min $\leq$ time	0
d13.6	Md13.6	Nv	Ed13.6	criteria $<$ 2	0
				2 $\leq$ criteria $<$ 3	0.25
				3 $\leq$ criteria $<$ 6	0.35
				6 $\leq$ criteria	0.5
d13.7	Md13.7	Av	Ed13.7	mass $\leq$ 200 g	0.5
				200 g $\leq$ mass $\leq$ 350 g	0.35
				350 g $\leq$ mass $\leq$ 2175 g	0.15
				2175 g $\leq$ mass	0
d13.8	Md13.8	Av	Ed13.8	volume $\leq$ 250 000 mm ³	0.5
				250 000 mm ³ $\leq$ volume $\leq$ 350 000 mm ³	0.35
				350 000 mm ³ $\leq$ volume $\leq$ 2 175 000 mm ³	0.15
				2 175 000 mm ³ $\leq$ volume	0

C.4 Initial Cost

Application: If one looks at the *Initial Cost (d21)* which is a sub-attribute of the *Cost* attribute we can define the following:



Table C-4: MCDA steps 4, 5 - Initial Cost

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d21					
d21.1	Md21.1	Av	Ed21.1	cost ≤ R 1000	1.00
				R 1000 ≤ cost ≤ R 4000	0.75
				R 4000 ≤ cost ≤ R 8000	0.50
				R 8000 ≤ cost	0.10
d21.2	Md21.2	Av	Ed21.2	cost ≤ R 1000	
				R 1000 ≤ cost ≤ R 4000	
				R 4000 ≤ cost ≤ R 8000	
				R 8000 ≤ cost	
d21.3	Md21.3	Av	Ed21.3	Nothing extra	1.00
d21.4	Md21.4	Av	Ed21.4	Nothing extra	1.00
				cost ≤ R 500	0.80
				R 500 ≤ cost ≤ R 2000	0.50
				R 2000 ≤ cost	0.30
d21.5	Md21.5	Av	Ed21.5	Nothing extra	1.00
				cost ≤ R 500	0.80
				R 500 ≤ cost ≤ R 2000	0.50
				R 2000 ≤ cost	0.30

C.5 Connection cost

Application: looking at the *Connection Cost (d22)* which is a sub-attribute of the *Cost* attribute, the following can be defined:

Table C-5: MCDA steps 4, 5 - Connection Cost

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d22					
d22.1	Md22.1	Av	Ed22.1	Nothing extra	1.00
				cost ≤ R 100	0.80
				R 100 ≤ cost	0.50
d22.2	Md22.2	Av	Ed22.2	Nothing extra	1.00
				cost ≤ R 100	0.80
				R 100 ≤ cost	0.50



C.6 Usage Cost

Application: looking at the *Usage Cost (d23)* which is a sub-attribute of the *Cost* attribute, the following can be defined:

Table C-6: MCDA steps 4, 5 - Usage Cost

Criteria variable	Measurement variable (Md)	Measurement value	Scale variable (Ed)	Classification field	Scale value
d23					
d23.1	Md23.1	Av	Ed23.1	cost ≤ R 100	1.00
				R 100 ≤ cost ≤ R 200	0.60
				R 200 ≤ cost	0.30
d23.2	Md23.2	Av	Ed23.2	Nothing extra	1.00
				cost ≤ R 100	0.80
				R 100 ≤ cost ≤ R 200	0.60
				R 200 ≤ cost	0.30
d23.3	Md23.3	Av	Ed23.3	Nothing extra	1.00
				cost ≤ R 100	0.80
				R 100 ≤ cost ≤ R 200	0.60
				R 200 ≤ cost	0.30
d23.4	Md23.4	Av	Ed23.4	Nothing extra	1.00
				cost ≤ R 100	0.80
				R 100 ≤ cost ≤ R 200	0.60
				R 200 ≤ cost	0.30

C.7 Summary

This type of measurement classification must be done for all the sub-attributes, but there seems to be a problem in classifying the *usability* attribute. The sub-attributes of the attribute can be measured only for certain actions and no actions are uniform for all working conditions. This is where MCDA reaches its limits and one has to find a method to overcome this problem.



Appendix D : Step 7 – Aggregation Method

D.1 Level 3 Aggregation algorithms

Processing Capability [$R11(a,d11)/Md11(a,d11)$] :

$$R11(a,d11) = [Md11.1(a)*W(a,d11.1)] + [Md11.2(a)*W(a,d11.2)] + ... \\ ... + [Md11.12(a)*W(a,d11.12)] + [Md11.13(a)*W(a,d11.13)]$$

$$\text{Where: } R11.2(a,d11.2)/Md11(a,d11.2) = [Md11.2.1(a)*W(a,d11.2.1)] + \\ [Md11.2.2(a)*W(a,d11.2.2)] + \\ [Md11.2.3(a)*W(a,d11.2.3)]$$

$$R11.2(a,d11.3)/Md11(a,d11.3) = [Md11.3.1(a)*W(a,d11.3.1)] + \\ [Md11.3.2(a)*W(a,d11.3.2)] + \\ [Md11.3.3(a)*W(a,d11.3.3)]$$

$$R11.2(a,d11.4)/Md11(a,d11.4) = [Md11.4.1(a)*W(a,d11.4.1)] + \\ [Md11.4.2(a)*W(a,d11.4.2)] + \\ [Md11.4.3(a)*W(a,d11.4.3)]$$

Connection Capability [$R12(a,d12)/Md12(a,d12)$] :

$$R12(a,d12) = [Md12.1(a)*W(a,d12.1)] + [Md12.2(a)*W(a,d12.2)] + ... \\ ... + [Md12.5(a)*W(a,d12.5)] + [Md12.6(a)*W(a,d12.6)]$$

Portability [$R13(a,d13)/Md13(a,d13)$] :

$$R13(a,d13) = [Md13.1(a)*W(a,d13.1)] + [Md13.2(a)*W(a,d13.2)] + ... \\ ... + [Md13.7(a)*W(a,d13.7)] + [Md13.8(a)*W(a,d13.8)]$$

Initial Cost [$R21(a,d21)/Md21(a,d21)$] :

$$R21(a,d21) = [Md21.1(a)*W(a,d21.1)] + [Md21.2(a)*W(a,d21.2)] + ... \\ ... + [Md21.4(a)*W(a,d21.4)] + [Md21.5(a)*W(a,d21.5)]$$

Connection Cost [$R22(a,d22)/Md22(a,d22)$] :

$$R22(a,d22) = [Md22.1(a)*W(a,d22.1)] + [Md22.2(a)*W(a,d22.2)]$$



Usage Cost $[R23(a,d23)/Md23(a,d23)]$:

$$R23(a,d23) = [Md23.1(a)*W(a,d23.1)] + [Md23.2(a)*W(a,d23.2)] + \\ [Md23.3(a)*W(a,d23.3)] + [Md23.4(a)*W(a,d23.4)]$$

Now that all of the aggregation algorithms up to level 3 criteria are in place, one can do the same for level 2 criterion.

D.2 Level 2 Aggregation algorithms

Specification $[R1(a,d1)/Md1(a,d1)]$:

$$R1(a,d1) = [Md11(a)*W(a,d11)] + [Md12(a)*W(a,d12)] + \\ [Md13(a)*W(a,d13)]$$

Cost $[R2(a,d2)/Md2(a,d2)]$:

$$R2(a,d2) = [Md21(a)*W(a,d21)] + [Md22(a)*W(a,d22)] + \\ [Md23(a)*W(a,d23)]$$

Now that all of the aggregation algorithms up to level 2 criteria are in place, one can do the same for level 1 criterions.

D.3 Level 1 Aggregation algorithm

Evaluation score $[R(a,d)/Md(a,d)]$:

$$R(a,d) = [Md1(a)*W(a,d1)] + [Md2(a)*W(a,d2)] + \\ [Md3(a)*W(a,d3)]$$

Where $Md3(a)$ is the scoring value that will be returned from the UCN evaluation model.



Appendix E : Step 3 – Criteria Definition/Measurement Score

In the following chapter the focus will be on the “full text” version of steps 4 and 5 of the MCDA model that were discussed in the previous chapter. In this appendix a full explanation of exactly how the scoring criteria boundaries for each criterion were determined and what is measured in each criterion (the criterion definition).

E.1 Experimental setup conditions

Date	: 2004-04-01 to 2004-05-30
Time of day	: 9:00 – 12:00 and 14:00 to 16:00
Environment	: North West University - Potchefstroom Campus, School of Electric & Electronic Engineering offices.
Distance to closest GSM tower	: 100m to 200m

E.2 Example for determining of criteria boundaries

The scoring criteria is created from a density distribution figure (e.g. Figure E-1) that was calculated from data that was collected from a wide range of field units, the units ranging from cell phones, PDA's to laptops.

On the density distribution figure one can see two lines, of which one is a normalized version of the other (the one with the biggest amplitude is the normalized one, this line is used in the selection of the scoring boundaries).

The criterion for scoring is selected according to the density plot in Figure E-1.

- The highest score (0.5) is awarded if the unit performs better than the point in which the density plot reaches 100 %.
- The average score (0.35) is awarded to the unit if its performance falls between 100% and 60% in the density plot or the centre between 3 times the



point at which the maximum point in the density plot was reached and the maximum point at which the density plot reaches 60% (if the boundary selected is smaller than the 60% point).

- The below average score (0.15) is awarded to the unit if its performance falls between 60% and 10% in the density plot or the centre between 3 times the point that was selected in the previous upper boundary and the maximum point at which the density plot reaches 10% (if the boundary selected is smaller than the 10% point).
- The bad score (0) is awarded to the unit if its performance falls between 10% and 0% in the density plot

The multiplication factor of “3” that was used in the above section can be derived from calculation of the probability density plot. In the calculation of the probability density plot an absolute range of values/boundaries was determined “intervals = (max-min)/20”. The deviation spread was selected to be over 3 intervals, thus this allows one to select the multiplication factor up to 3.

Example:

Table E-1: Example for determining boundaries

Open time	score
time $\leq$ boundary 1	0.5
boundary 1 $\leq$ time $\leq$ boundary 2	0.35
boundary 2 $\leq$ time $\leq$ boundary 3	0.15
boundary 3 $\leq$ time	0

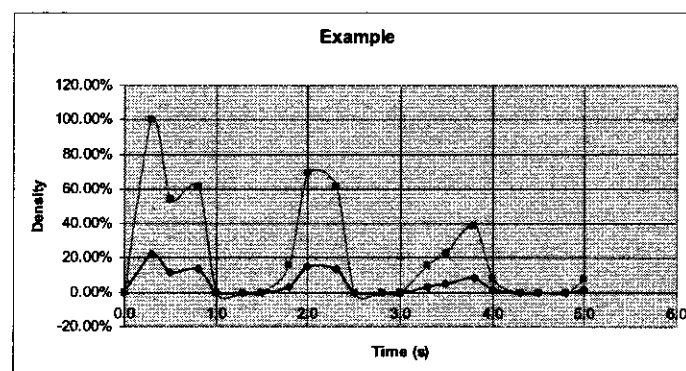


Figure E-1: Example for determining boundaries



Boundary 1: time = 0.25 s at 100 %

Boundary 2: time = 2 s at 60%

$$3 * \text{boundary 1} = 0.75 \text{ s}$$

$$\begin{aligned} \text{Thus boundary 2} &= (3 * \text{boundary 1}) [(\text{time at 60\%}) + (3 * \text{boundary 1})] / 2 \\ &= (0.75) + [(2 - 0.75)] / 2 \\ &= 1.375 \text{ s} \end{aligned}$$

Boundary 3: time = 4.0 s at 10%

$$3 * \text{boundary 2} = 4.125 \text{ s}$$

Because: time (10%) < 4.125

Thus boundary 3 = 4 s

Table E-2: Example boundaries

Open time	score
time $\leq$ 0.25 s	0.5
0.25 s $\leq$ time $\leq$ 1.375 s	0.35
1.375 s $\leq$ time $\leq$ 4 s	0.15
4 s $\leq$ time	0

E.3 Specification - Processing Capability

E.3.1 File type handling

E.3.1.1 Criteria definition

The different type of files that the field units could be handling ranges from short text (.txt) only files up to Microsoft Word (.doc) or Adobe acrobat (.pdf) that contain text and pictures (this could be road maps to the next destination or technical schematics needed for the next task). This criterion consists of four criteria against which the field units are evaluated. The four types of documents can be seen in Table E-2.

E.3.1.2 Criteria parameters/scoring determination

The scoring of the field units will depend on the file types the unit is capable of processing (displaying the document). The file types are arranged according to processing power needed, thus the field units that are capable of handling the last documents (.pdf & .doc) will get the highest score.



Table E-3: File type handling

File types	score
Text only (characters < 300)	0.1
Text only (characters $\geq$ 300)	0.2
Text + picture (separate: text + jpeg, bmp)	0.3
Text + picture (single file: .doc, .pdf)	0.4

E.3.2 File open time

E.3.2.1 Criteria definition

This criterion is divided into the three types of files which are: Text only (characters < 300), Text only (characters $\geq$ 300) and Text + picture (single file: .doc, .pdf). The “file open time” is time it takes the field unit to open the document that is already on memory/hard drive (does not have to be downloaded) from the moment the operator selects the file to be opened to the time the file is displayed on the screen of the field unit and is ready to be read.

E.3.2.2 Criteria parameters/scoring determination

File type1:

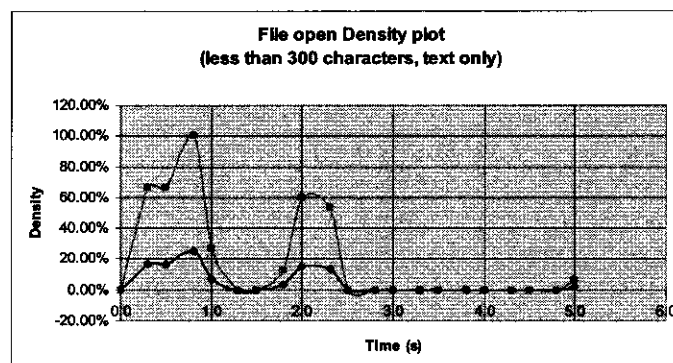


Figure E-2: File open time - Probability density plot (less than 300 character, text only)

Boundary 1: time = 0.75 s at 100 %

Boundary 2: time = 2 s at 60%

$$3 * \text{boundary 1} = 0.225 \text{ s}$$

Thus boundary 2 = 2 s

Boundary 3: time = 2.4 s at 10%

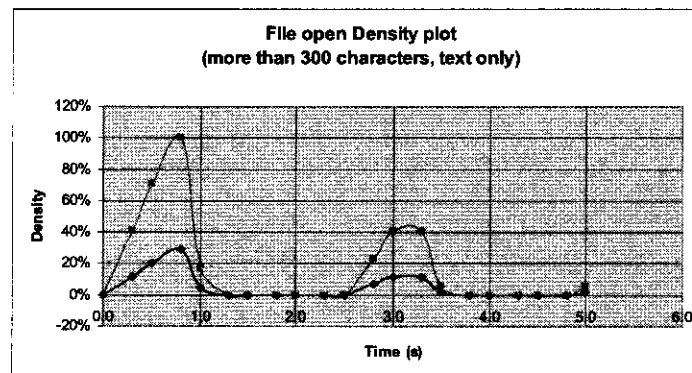
$$3 * \text{boundary 2} = 7.5 \text{ s}$$

Thus boundary 3 = 2.4 s



Table E-4: File open time - Scoring boundaries (less than 300 characters, text only)

Open time	score
time $\leq$ 0.75 s	0.5
0.8 s $\leq$ time $\leq$ 2 s	0.35
2 s $\leq$ time $\leq$ 2.4 s	0.15
2.4 s $\leq$ time	0

File type 2:**Figure E-3: File open time - Probability density plot (more than 300 characters, text only)**

Boundary 1: time = 0.75 s at 100 %

Boundary 2: time = 0.8 s at 60%

$$3 * \text{boundary 1} = 0.225 \text{ s}$$

Thus boundary 2 = 0.8 s

Boundary 3: time = 3.5 s at 10%

$$3 * \text{boundary 2} = 2.4 \text{ s}$$

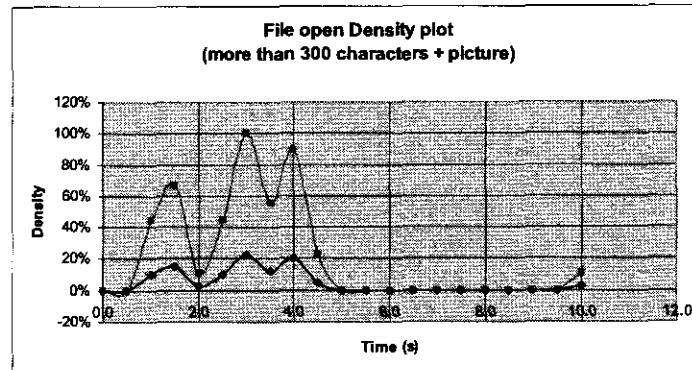
$$\text{Thus boundary 3} = (2.4) + [(3.5)-(2.4)]/2 \\ = 2.95 \text{ s}$$

Thus boundary 3 = 2.4 s

Table E-5: File open scoring boundaries (more than 300 characters, text only)

Open time	score
time $\leq$ 0.8 s	0.5
0.8 s $\leq$ time $\leq$ 1 s	0.35
1 s $\leq$ time $\leq$ 2.95 s	0.15
2.95 s $\leq$ time	0



File type 3:**Figure E-4: File open time - Probability density plot (more than 300 characters + picture)**

Boundary 1: time = 3 s at 100 %

Boundary 2: time = 4.25 s at 60%

$$3 * \text{boundary 1} = 9\text{s}$$

$$\text{Thus boundary 2} = 4.25 \text{ s}$$

Boundary 3: time = 4.4 s at 10%

$$3 * \text{boundary 2} = 12.75 \text{ s}$$

Thus boundary 3 = 4.4 s

Table E-6: File open time - Scoring boundaries (more than 300 characters + picture)

Open time	score
time $\leq$ 3 s	0.5
3 s $\leq$ time $\leq$ 4.25 s	0.35
4.25 s $\leq$ time $\leq$ 4.4 s	0.15
4.4 s $\leq$ time	0

E.3.3 File close time**E.3.3.1 Criteria definition**

This criterion is divided into the three types of files which are: Text only (characters < 300), Text only (characters $\geq$ 300) and Text + picture (single file: .doc, .pdf). The “file close time” is the time it takes the field unit to close the document (the selected file that is already open), from the moment the operator enters the command that the unit should close the file to the moment the file is completely closed and the unit hands control over to the operator.



E.3.3.2 Criteria parameters/scoring determination

File type 1:

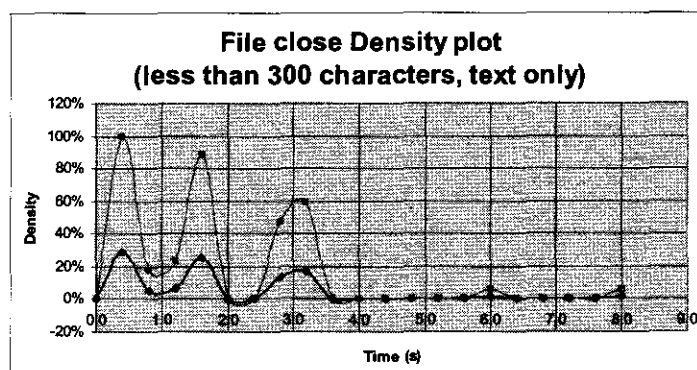


Figure E-5: File close time - Probability density plot (less than 300 character, text only)

Boundary 1: time = 0.4 s at 100 %

Boundary 2: time = 3.2 s at 60%

$$3 * \text{boundary 1} = 1.2 \text{ s}$$

$$\begin{aligned} \text{Thus boundary 2} &= (1.2) + [(3.2)-(1.2)]/2 \\ &= 2.2 \text{ s} \end{aligned}$$

Boundary 3: time = 3.5 s at 10%

$$3 * \text{boundary 2} = 6.6 \text{ s}$$

$$\text{Thus boundary 3} = 3.5 \text{ s}$$

Table E-7: File close time - Scoring boundaries (less than 300 characters, text only)

Open time	score
time $\leq$ 0.4 s	0.5
0.4 s $\leq$ time $\leq$ 2.2 s	0.35
2.2 s $\leq$ time $\leq$ 3.5 s	0.15
3.5 s $\leq$ time	0

File type 2:

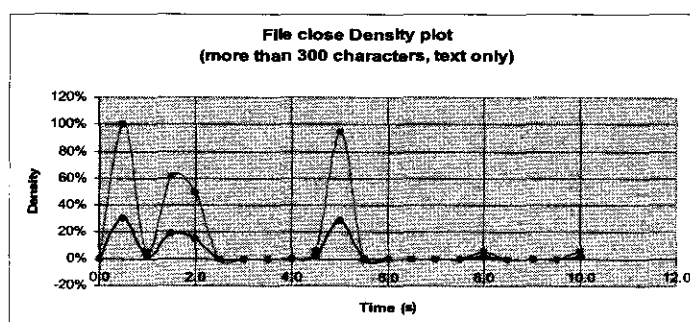


Figure E-6: File close time - Probability density plot (more than 300 characters, text only)



Boundary 1: time = 0.5 s at 100 %

Boundary 2: time = 5.2 s at 60%

$$3 * \text{boundary 1} = 1.5 \text{ s}$$

$$\text{Thus boundary 2} = (1.5) + [(5.2)-(1.5)]/2 \\ = 3.35 \text{ s}$$

Boundary 3: time = 5.4 s at 10%

$$3 * \text{boundary 2} = 10.05 \text{ s}$$

$$\text{Thus boundary 3} = 5.4 \text{ s}$$

Table E-8: File close time - Scoring boundaries (more than 300 characters, text only)

Open time	score
time $\leq$ 0.5 s	0.5
0.5 s $\leq$ time $\leq$ 3.35 s	0.35
3.35 s $\leq$ time $\leq$ 5.4 s	0.15
5.4 s $\leq$ time	0

File type 3:

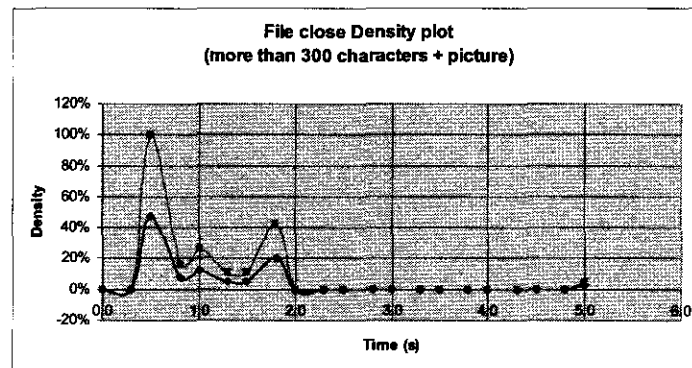


Figure E-7: File close time - Probability density plot (more than 300 characters + picture)

Boundary 1: time = 0.5 s at 100 %

Boundary 2: time = 0.625 s at 60%

$$3 * \text{boundary 1} = 1.5 \text{ s}$$

$$\text{Thus boundary 2} = 0.625 \text{ s}$$

Boundary 3: time = 1.8 s at 10%

$$3 * \text{boundary 2} = 1.875 \text{ s}$$

$$\text{Thus boundary 3} = 1.8 \text{ s}$$

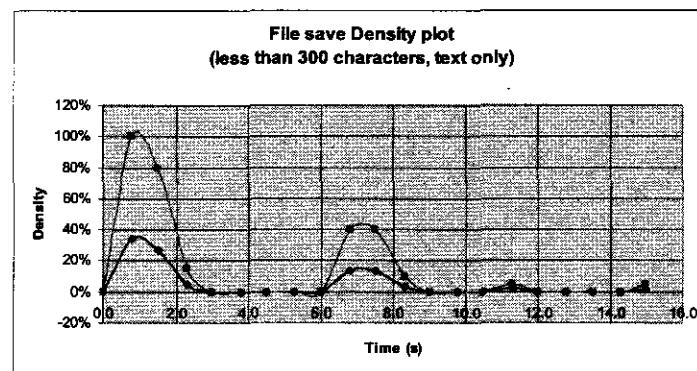


Table E-9: File close time - Scoring boundaries (more than 300 characters + picture)

Open time	score
time $\leq$ 0.5 s	0.5
0.5 s $\leq$ time $\leq$ 0.625 s	0.35
0.625 s $\leq$ time $\leq$ 1.8 s	0.15
1.8 s $\leq$ time	0

E.3.4**E.3.5 File save time****E.3.5.1 Criteria definition**

This criterion is also divided into the three types of files which are: Text only (characters < 300), Text only (characters $\geq$ 300) and Text + picture (single file: .doc, .pdf). The “file save time” is time it takes the field unit to save an opened document, from the moment the operator enters the command that the unit should save the file/document (to the units memory/hard drive) to the moment the file is completely saved and the unit hands control back to the operator.

E.3.5.2 Criteria parameters/scoring determination**Figure E-8: File save time - Probability density plot (less than 300 character, text only)**

Boundary 1: time = 0.25 s at 100 %

Boundary 2: time = 2 s at 60%

$$3 * \text{boundary 1} = 0.75 \text{ s}$$

$$\begin{aligned}
 \text{Thus boundary 2} &= (3 * \text{boundary 1}) + [(\text{time at 60\%}) - (3 * \text{boundary 1})] / 2 \\
 &= (0.75) + [(2 - 0.75)] / 2 \\
 &= 1.375 \text{ s}
 \end{aligned}$$



Boundary 3: time = 4.0 s at 10%
 $3 * \text{boundary 2} = 4.125 \text{ s}$
 Because: time (10%) < 4.125
 Thus boundary 3 = 4 s

Table E-10: File save time - Scoring boundaries (less than 300 characters, text only)

Open time	score
time $\leq$ 0.75 s	0.5
0.75 s $\leq$ time $\leq$ 1.7 s	0.35
1.7 s $\leq$ time $\leq$ 6.65 s	0.15
6.65 s $\leq$ time	0

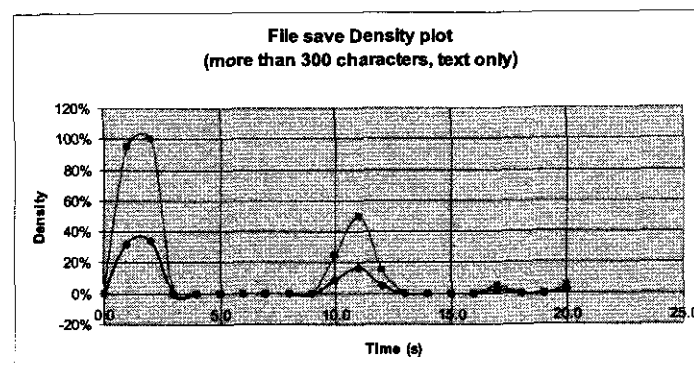


Figure E-9: File save time - Probability density plot (more than 300 characters, text only)

Boundary 1: time = 2 s at 100 %
 Boundary 2: time = 2.3 s at 60%
 $3 * \text{boundary 1} = 6 \text{ s}$
 Thus boundary 2 = 2.3 s

$$= (0.75) + [(2 - 0.75)]/2$$

$$= 1.375 \text{ s}$$

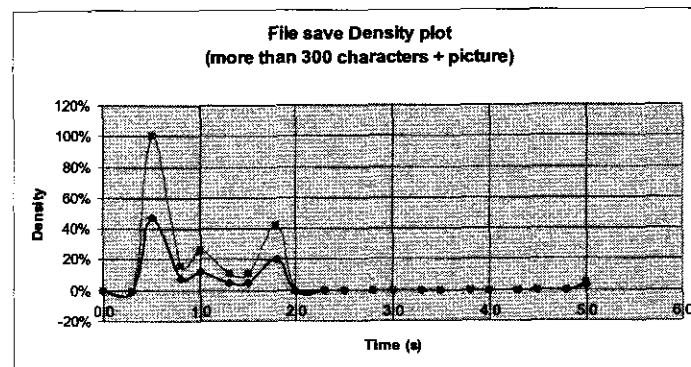
 Boundary 3: time = 12.5 s at 10%
 $3 * \text{boundary 2} = 6.9 \text{ s}$
 Thus boundary 3 = $(6.9) + [(12.5) - (6.9)]/2$

$$= 9.7 \text{ s}$$



Table E-11: File save time - Scoring boundaries (more than 300 characters, text only)

Open time	score
$\text{time} \leq 2 \text{ s}$	0.5
$2 \text{ s} \leq \text{time} \leq 2.3 \text{ s}$	0.35
$2.3 \text{ s} \leq \text{time} \leq 9.7 \text{ s}$	0.15
$9.7 \text{ s} \leq \text{time}$	0

**Figure E-10: File save time - Probability density plot (more than 300 characters + picture)**

Boundary 1: $\text{time} = 0.5 \text{ s}$ at 100 %

Boundary 2: $\text{time} = 0.625 \text{ s}$ at 60%

$$3 * \text{boundary 1} = 0.15 \text{ s}$$

$$\text{Thus boundary 2} = 0.625 \text{ s}$$

Boundary 3: $\text{time} = 1.9 \text{ s}$ at 10%

$$3 * \text{boundary 2} = 1.8 \text{ s}$$

$$\begin{aligned} \text{Thus boundary 3} &= 1.8 + [(1.9) - (1.8)] / 2 \\ &= 1.85 \text{ s} \end{aligned}$$

Table E-12: File save - Scoring boundaries (more than 300 characters + picture)

Open time	score
$\text{time} \leq 0.5 \text{ s}$	0.5
$0.5 \text{ s} \leq \text{time} \leq 0.625 \text{ s}$	0.35
$0.625 \text{ s} \leq \text{time} \leq 1.85 \text{ s}$	0.15
$1.85 \text{ s} \leq \text{time}$	0



E.3.6 GPRS Web access time

E.3.6.1 Criteria definition

The “GPRS web access time” is time it takes the field unit to open a new webpage (via a GPRS connection) after the field unit has already made a GPRS connection, from the moment the operator enters the webpage address (e.g. www.google.com) and presses enter or go to the time the webpage is completely displayed on the field unit screen and the unit hands control back to the operator.

E.3.6.2 Criteria parameters/scoring determination

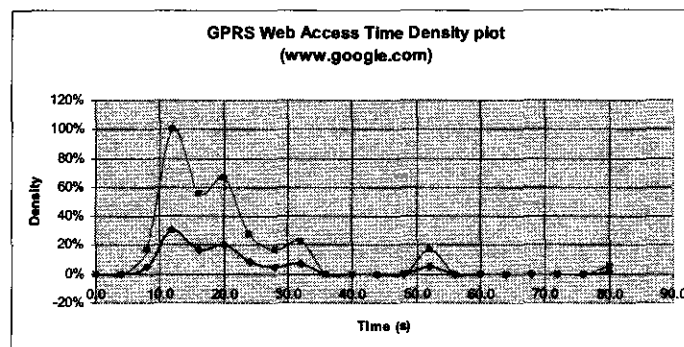


Figure E-11: GPRS web access time - Probability density plot

Boundary 1: time = 12 s at 100 %

Boundary 2: time = 22 s at 60%

$3 * \text{boundary 1} = 36 \text{ s}$

Thus boundary 2 = 22s

Boundary 3: time = 34 s at 10%

$3 * \text{boundary 2} = 34.5 \text{ s}$

Thus boundary 3 = 34.5 s

Table E-13: GPRS web access time - Scoring boundaries

Open time	score
time $\leq$ 12 s	0.5
12 s $\leq$ time $\leq$ 22 s	0.35
22 s $\leq$ time $\leq$ 34.5 s	0.15
34.5 s $\leq$ time	0



E.3.7 Short range communication Web access time

E.3.7.1 Criteria definition

The “Short rang communication web access time” is time it takes the field unit to open a new webpage (via a Wi-Fi, IRDA or data cable connection) after the field unit has already made a connection, from the moment the operator enters the webpage address (e.g. www.google.com) and presses enter or go to the time the webpage is completely displayed on the field unit screen and the unit hands control back to the operator.

E.3.7.2 Criteria parameters/scoring determination

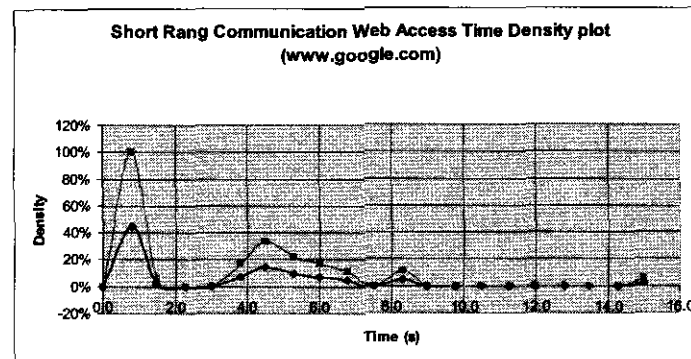


Figure E-12: Short rang communication web access time - Probability density plot

Boundary 1: time = 0.4 s at 100 %

Boundary 2: time = 0.6 s at 60%

$$3 * \text{boundary 1} = 1.8 \text{ s}$$

$$\text{Thus boundary 2} = 0.6 \text{ s}$$

Boundary 3: time = 8.2 s at 10%

$$3 * \text{boundary 2} = 1.8 \text{ s}$$

$$\begin{aligned} \text{Thus boundary 3} &= 1.8 + [(8.2) - (1.8)] / 2 \text{ s} \\ &= 5 \text{ s} \end{aligned}$$

Table E-14: Short rang communication web access time - Scoring boundaries

Open time	score
time $\leq$ 0.4 s	0.5
4 s $\leq$ time $\leq$ 0.6 s	0.35
0.6 s $\leq$ time $\leq$ 5 s	0.15
5 s $\leq$ time	0



E.3.8 File compression availability

E.3.8.1 Criteria definition

This criterion is only an additional feature; it does not fall under critical criteria (very important). This criteria only checks to see if the field unit is capable of data compression and decompression, nothing more. If the field unit supports some type of compression/decompression capability, it would be able to send and receive a larger amount of data by using less bandwidth.

E.3.8.2 Criteria parameters/scoring determination

The scoring of the field units will depend on the capability of the field unit to support compression and decompression software. If the field unit supports compression and decompression it will score 1/1 and if it does not support compression and decompression it will score 0/1.

Table E-15: File compression availability

Support file compression and decompression	score
yes	1.00
no	0.00

E.3.9 Application switching

E.3.9.1 Criteria definition

One of the appealing features of modern user interfaces (GUI) is the ability they give to switch between different applications without having to save everything one's busy with and close the one application, before opening the next application. Thus application switching gives one the ability to deal with many applications and suspend and reactivate them as required.

E.3.9.2 Criteria parameters/scoring determination

The scoring of the field units will depend on the capability of the field unit to support application switching. If the field unit supports application switching it will score 1/1 and if it does not support compression and decompression it will score 0/1.



Table E-16: File compression availability

Support application switching	score
yes	1.00
no	0.00

E.3.10 Graphic display time (.jpeg)

E.3.10.1 Criteria definition

In the first criteria that was discussed the field units were tested against four types of file that the field units could be able to handle. The third choice in Table E- was “Text + picture (separate: text + jpeg, bmp)”. The text section was already contained in “file open” criteria. In this criterion the ability of the field unit to process the graphic file type “.jpeg” will be measured.

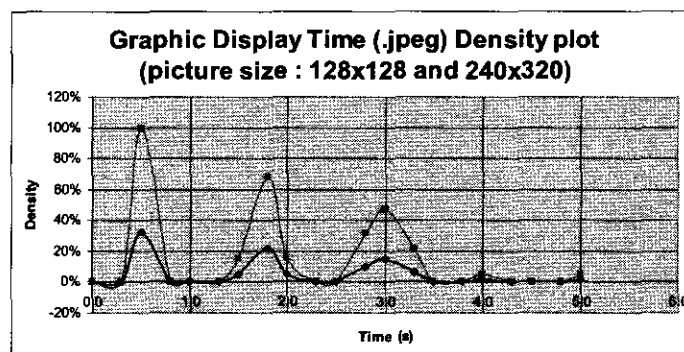


Figure E-13: Graphic display time (.jpeg) - Probability density plot

The “Graphic display time (.jpeg)” is time it takes the field unit to open a new “.jpeg” file, from the moment the operator inserts the command to open the file to the time the “.jpeg” is completely displayed on the field unit screen and the unit hands control back to the operator. The size of the pictures that were used to construct the density plot varies from 128x128 dots to 240x320 dots. This is done because it is virtually impossible to display a proper schematic/map in a 128x128 dots picture.

E.3.10.2 Criteria parameters/scoring determination

Boundary 1: time = 0.5 s at 100 %

Boundary 2: time = 1.85 s at 60%

$$3 * \text{boundary 1} = 1.5 \text{ s}$$

$$\text{Thus boundary 2} = (1.5) + [(1.85)-(1.6)]/2$$



$$= 1.625 \text{ s}$$

Boundary 3: time = 3.4 s at 10%

$$3 * \text{boundary 2} = 4.875 \text{ s}$$

Thus boundary 3 = 3.4 s

Table E-17: Graphic display time (.jpeg) - Scoring boundaries

Open time	score
time $\leq$ 0.5 s	0.5
0.5 s $\leq$ time $\leq$ 1.625 s	0.35
1.625 s $\leq$ time $\leq$ 3.4 s	0.15
3.4 s $\leq$ time	0

E.3.11 Graphic display time (.bmp)

E.3.11.1 Criteria definition

In the first criteria that was discussed the field units were tested against four types of file that the field units could be able to handle. The third choice in Table E- was “Text + picture (separate: text + jpeg, bmp)”. The text section was already contained in the “file open” criteria and in this criteria the ability of the field unit to process the graphic file type “.bmp” will be checked.

The “Graphic display time (.bmp)” is the time it takes the field unit to open a new “.bmp” file, from the moment the operator inserts the command to open the file to the time the “.bmp” is completely displayed on the field unit screen and the unit hands control back to the operator.

The size of the pictures that were used to construct the density plot varies from 128x128 dots to 240x320 dots. This is done because it is virtually impossible to display a proper schematic/map on a 128x128 dots picture.

E.3.11.2 Criteria parameters/scoring determination

Boundary 1: time = 0.4 s at 100 %

Boundary 2: time = 2.2 s at 60%

$$3 * \text{boundary 1} = 1.2 \text{ s}$$

$$\text{Thus boundary 2} = (1.2) + [(2.2)-(1.2)]/2$$

$$= 1.7 \text{ s}$$



Boundary 3: time = 6.6 s at 10%

$$3 * \text{boundary 2} = 4.1 \text{ s}$$

Thus boundary 3 = 6.6 s

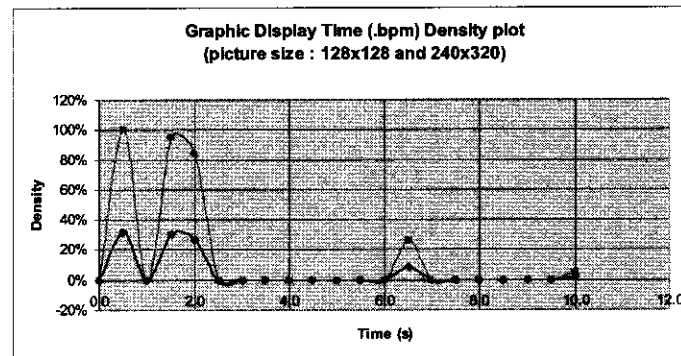


Figure E-14: Graphic display time (.bmp) - Probability density plot

Table E-18: Graphic display time (.bmp) - Scoring boundaries

Open time	score
time $\leq$ 0.4 s	0.5
0.4 s $\leq$ time $\leq$ 1.7 s	0.35
1.7 s $\leq$ time $\leq$ 6.6 s	0.15
6.6 s $\leq$ time	0

E.3.12

E.3.13 Graphic close time (.jpeg)

E.3.13.1 Criteria definition

In the first criteria that were discussed the field units were tested against four types of files that the field units could be able to handle. The third choice in Table E- was "*Text + picture (separate: text + jpeg, bmp)*". The text section was already contained in the "*file close*" criteria, in this criteria the ability of the field unit to process the graphic file type "*jpeg*" will be checked.

The "*Graphic close time (jpeg)*" is the time it takes the field unit to close a "*jpeg*" file that is already open, from the moment the operator inserts the command to close the file to the time the "*jpeg*" is completely closed and the unit hands control back to the operator.



The size of the pictures that were used to calculate the density plot varies from 128x128 dots to 240x320 dots. This is done because it is virtually impossible to display a proper schematic/map in a 128x128 dots picture.

E.3.13.2 Criteria parameters/scoring determination

Boundary 1: time = 1.375 s at 100 %

Boundary 2: time = 1.6 s at 60%

3 * boundary 1 = 4.125 s

Thus boundary 2 = 1.6 s

Boundary 3: time = 1.75 s at 10%

3 * boundary 2 = 4.8 s

Thus boundary 3 = 1.75 s

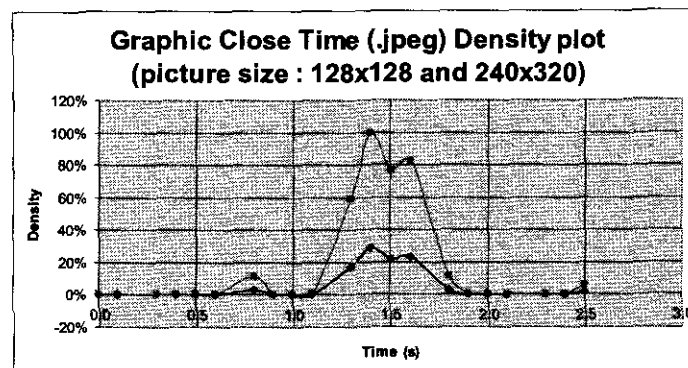


Figure E-15: Graphic close time (.jpeg) - Probability density plot

Table E-19: Graphic close time (.jpeg) - Scoring boundaries

Open time	score
time $\leq$ 1.375 s	0.5
1.375 s $\leq$ time $\leq$ 1.6 s	0.35
1.6 s $\leq$ time $\leq$ 1.75 s	0.15
1.75 s $\leq$ time	0

E.3.14 Graphic close time (.bmp)

E.3.14.1 Criteria definition

In the first criteria that were discussed the field units was tested against four types of files that the field units could be able to handle. The third choice in Table E- was



"Text + picture (separate: text + jpeg, bmp)". The text section was already contained in the "file close" criteria and in this criteria the ability of the field unit to process the graphic file type ".bmp" will be checked.

The "Graphic close time (.bmp)" is the time it takes the field unit to close a ".bmp" file that is already open, from the moment the operator inserts the command to close the file to the time the ".bmp" is completely closed and the unit hands control back to the operator.

E.3.14.2 Criteria parameters/scoring determination

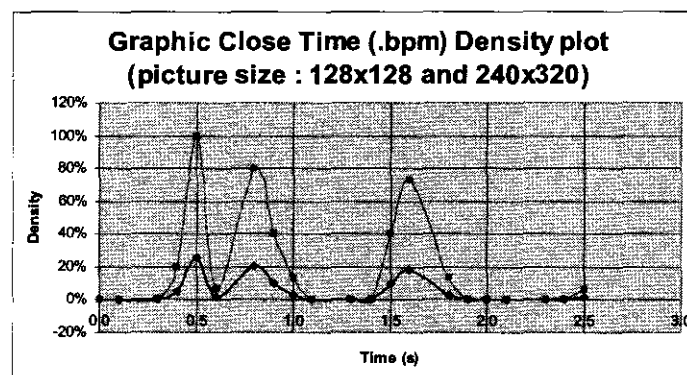


Figure E-16: Graphic display time (.bmp) - Probability density plot

Boundary 1: time = 0.5 s at 100 %

Boundary 2: time = 1.65 s at 60%

$$3 * \text{boundary 1} = 1.5 \text{ s}$$

$$\begin{aligned} \text{Thus boundary 2} &= (1.5) + [(1.65)-(1.5)]/2 \\ &= 1.575 \text{ s} \end{aligned}$$

Boundary 3: time = 1.8 s at 10%

$$3 * \text{boundary 2} = 4.725 \text{ s}$$

$$\text{Thus boundary 2} = 1.8 \text{ s}$$

Table E-20: Graphic close time (.bmp) - Scoring boundaries

Open time	score
time $\leq$ 0.5 s	0.5
0.5 s $\leq$ time $\leq$ 1.575 s	0.35
1.575 s $\leq$ time $\leq$ 1.8 s	0.15
1.8 s $\leq$ time	0



E.3.15 Storage capacity

E.3.15.1 Criteria definition

The storage capacity of the field units is not of utmost importance but the field units should be able to save a certain amount of messages and data on the unit itself. The storage of data is needed to help save the amount of data that has to be sent to the field unit. If the basic datasheet that the field operator uses can be saved on the unit itself by means of a short range communication channel, less has to be sent to the field operator to complete the current task. The amount of files (or size) that can be saved on the field unit will determine the score that the unit will get for this criterion. The criterion boundaries are logically chosen (rule of thumb).

E.3.15.2 Criteria parameters/scoring determination

Table E-21: Storage capacity - Scoring boundaries

Storage capacity	score
text messages > 1000	0.50
150 < text messages < 1000	0.35
text messages < 150	0.15

E.4 Specification - Connection Capability

E.4.1 GPRS connection type

E.4.1.1 Criteria definition

GPRS allows a single mobile station to transmit on multiple time slots of the same TDMA frame. This results in a flexible channel allocation: one to eight time slots per TDMA frame can be allocated to one mobile station. Moreover, uplink and downlink channels are allocated separately. Thus this criterion takes the number of downlink channels that are allocated to the specific unit into account. The probability density plot in Figure E-17 is calculated from a survey of 60 different field units.



E.4.1.2 Criteria parameters/scoring determination

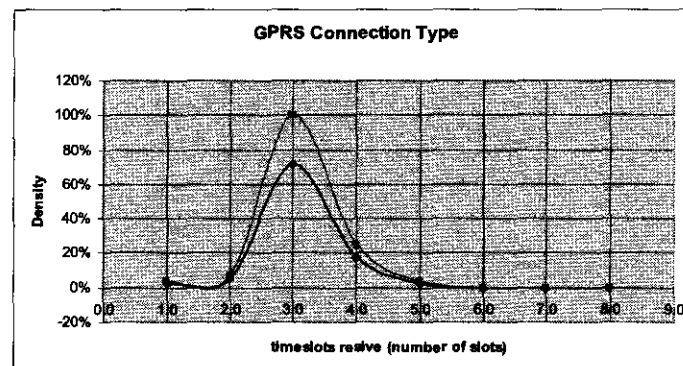


Figure E-17: GPRS connection type – Probability density plot

Table E-22: GPRS connection type - Scoring boundaries

Time slots	score
Down link slots < 2	0
$2 \leq$ Down link slots < 3	0.15
$3 \leq$ Down link slots < 4	0.3
$4 \leq$ Down link slots	0.5

E.4.2 GPRS connection time

E.4.2.1 Criteria definition

The “*GPRS connection time*” is the time it takes the field unit to setup a new GPRS connection, from the moment the operator inserts the command to start the connection to the moment the field unit indicates that the connection is established.

E.4.2.2 Criteria parameters/scoring determination

Boundary 1: time = 6 s at 100 %

Boundary 2: time = 16.5 s at 60%

$3 * \text{boundary 1} = 18 \text{ s}$

Thus boundary 2 = 16.5 s

Boundary 3: time = 18 s at 10%

$3 * \text{boundary 2} = 49.5 \text{ s}$

Thus boundary 3 = 18 s



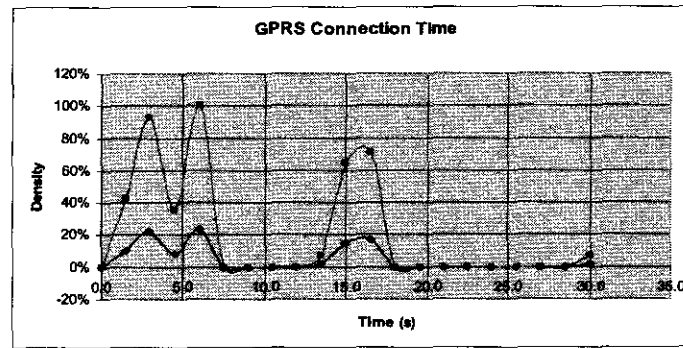


Figure E-18: GPRS connection time – Probability density plot

Table E-23: GPRS connection time - Scoring boundaries

Open time	score
$\text{time} \leq 6 \text{ s}$	0.5
$6 \text{ s} \leq \text{time} \leq 16.5 \text{ s}$	0.35
$16.5 \text{ s} \leq \text{time} \leq 18 \text{ s}$	0.15
$18 \text{ s} \leq \text{time}$	0

E.4.3 GPRS connection speed

E.4.3.1 Criteria definition

The “GPRS connection speed” is the theoretical data rate that could be expected from the different field units. These rates could vary because of different numbers of time slots that are available on the different field units and the amount of processing power that is assigned to the connection at different times.

E.4.3.2 Criteria parameters/scoring determination

This criterion's scoring boundaries are determined opposite the example given (at the beginning of the appendix) because in this criterion the higher the data rate the better the score.

Boundary 1: Data rate = 40 kbps at 100 %

Boundary 2: Data rate = 38 kbps s at 60%

boundary1 /3 = 13.33 kbps

Thus boundary 2 = 38 kbps

Boundary 3: Data rate = 27.5 s at 10%

Boundary 2 /3 = 12.6 kbps

Thus boundary 3 = 27.5 s



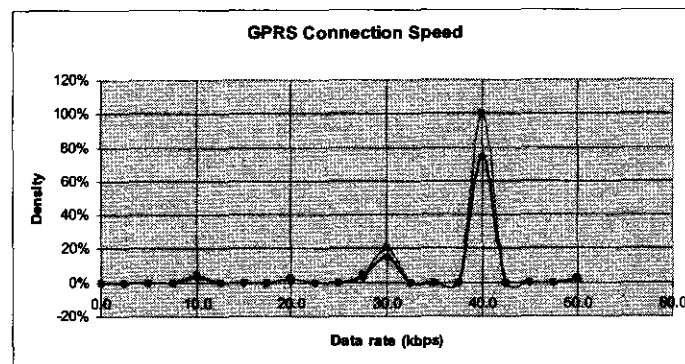


Figure E-19: GPRS connection speed – Probability density plot

Table E-24: GPRS connection time - Scoring boundaries

Connection speed	score
Data rate $\leq$ 27.5 kbps	0
27.5 kbps $\leq$ Data rate $\leq$ 38 kbps	0.15
38 kbps $\leq$ Data rate $\leq$ 40 kbps	0.35
40 kbps $\leq$ Data rate	0.5

E.4.4 Short range communication availability

E.4.4.1 Criteria definition

The “Short range communication availability” is the criterion in which one takes a look at the different types of short range communication capabilities and the availability of each of these communication channels on each unit.

E.4.4.2 Criteria parameters/scoring determination

A data cable, IRDA port, Bluetooth and Wi-Fi connection point are to be taken into consideration. The scores of a field unit are determined according to the availability of different connection types.

Table E-25: Short range communication specifications

Connection type	Data rate (kbps)	Reception distance
Data cable	11 000 - 48 000	1 m
IRDA	1 150 - 4 000	0.3 m
Bluetooth	723 - 1 000	10 m
Wi-Fi	1 000-2 000	100m



Table E-26 : Short range communication - Scoring boundaries

Open time	score
Data cable & Wi-Fi	0.4
Data cable & Bluetooth	0.3
Data cable & IRDA	0.2
Data cable only	0.1

E.4.5 Short range communication connection time

E.4.5.1 Criteria definition

The "Short range communication time" is the criterion in which one looks at the connection time of different types of short range communication capabilities. This is the time from the moment the operator inserts the command to start the connection to the moment the field unit indicates that the connection is established. The probability density plot in Figure E-20 is calculated using four types of short range communication technologies (data cable, IrDA, bluetooth and Wi-Fi).

E.4.5.2 Criteria parameters/scoring determination

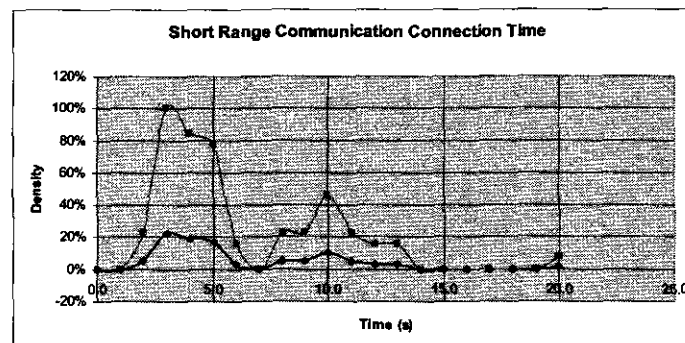


Figure E-20: Short range communication connection time – Probability density plot

Boundary 1: time = 3 s at 100 %

Boundary 2: time = 5.3 s at 60%

$3 * \text{boundary 1} = 9 \text{ s}$

Thus boundary 2 = 5.3 s

Boundary 3: time = 13.5 s at 10%

$3 * \text{boundary 2} = 15.9 \text{ s}$

Thus boundary 3 = 13.5 s



Table E-27: Short range communication connection time - Scoring boundaries

Open time	score
$\text{time} \leq 3 \text{ s}$	0.5
$3 \text{ s} \leq \text{time} \leq 5.3 \text{ s}$	0.35
$5.3 \text{ s} \leq \text{time} \leq 13.5 \text{ s}$	0.15
$13.5 \text{ s} \leq \text{time}$	0

E.4.6 Short range communication Connection speed

E.4.6.1 Criteria definition

The “*Short range communication speed*” is the criterion in which one looks at data rates that can be achieved with different types of short range communication capabilities on the field units. The probability density plot in Figure E-21 is calculated using four types of short range communication technologies (Bluetooth, IrDA and Wi-Fi).

E.4.6.2 Criteria parameters/scoring determination

This criterion's scoring boundaries are determined in opposite to the example given because in this criterion the higher the data rate the better the score.

Boundary 1: Data rate = 2000 kbps at 100 %

Boundary 2: Data rate = 1200 kbps at 60%

Boundary 1 / 3 = 666 kbps

Thus boundary 2 = 1200 kbps

Boundary 3: Data rate = 600 kbps at 10%

Boundary 2 / 3 = 400 kbps

Thus boundary 3 = 600 kbps



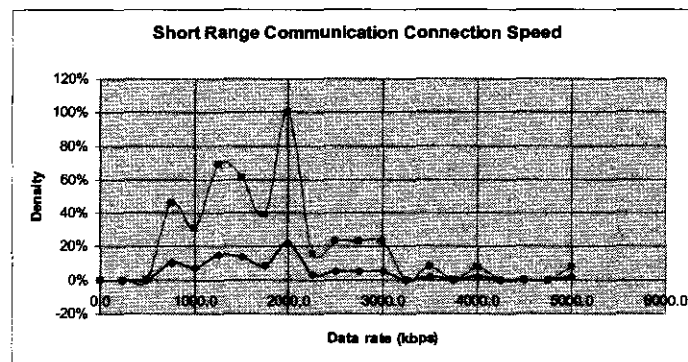


Figure E-21: Short range communication connection speed – Probability density plot

Table E-28: Short range communication connection speed - Scoring boundaries

Connection speed	score
Data rate $\leq$ 600 kbps	0
600 kbps $\leq$ Data rate $\leq$ 1200 kbps	0.15
1200 kbps $\leq$ Data rate $\leq$ 2000 kbps	0.35
2000 kbps $\leq$ Data rate	0.5

E.5 Specification - Portability

E.5.1 Battery usage/talk time

E.5.1.1 Criteria definition

The “battery usage/talk time” is the criterion in which one looks at the time the battery will last for one charge by using the field unit continually until the unit switches off because the battery’s voltage-current level is too low to support the field unit any more.

E.5.1.2 Criteria parameters/scoring determination

This criterion’s scoring boundaries are determined opposite to the example given because in this criterion the longer the battery usage time, the better the score.



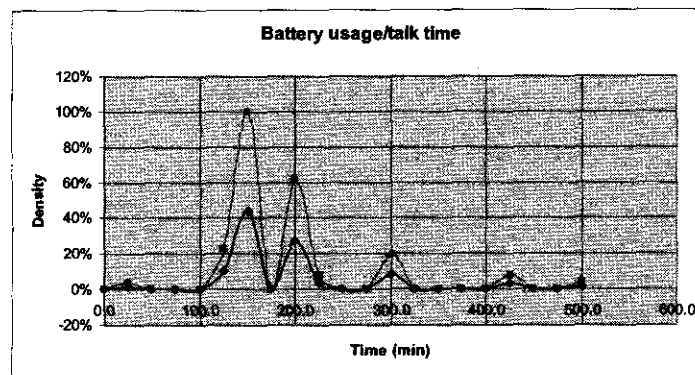


Figure E-22: Battery usage/talk time – Probability density plot

Boundary 1: time = 150 min at 100 %

Boundary 2: time = 137.5 min at 60%

Boundary 1 / 3 = 50 min

Thus boundary 2 = 137.5 min

Boundary 3: time = 112.5 min at 10%

Boundary 2 / 3 = 45.8 min

Thus boundary 3 = 112.5 min

Table E-29: Battery usage/talk time - Scoring boundaries

Open time	score
time $\leq$ 112.5 min	0
112.5 min $\leq$ time $\leq$ 137.5 min	0.15
137.5 min $\leq$ time $\leq$ 150 min	0.35
150 min $\leq$ time	0.5

E.5.2 Battery standby time

E.5.2.1 Criteria definition

The “battery standby time” is the criterion in which one looks at the time the battery will last for one charge by putting the field unit on and waiting until the unit switches off because the battery’s voltage-current level is too low to support the field unit any more.

E.5.2.2 Criteria parameters/scoring determination

This criterion’s scoring boundaries are determined in reverse of the example given because in this criterion the longer the battery standby time is, the better the score.



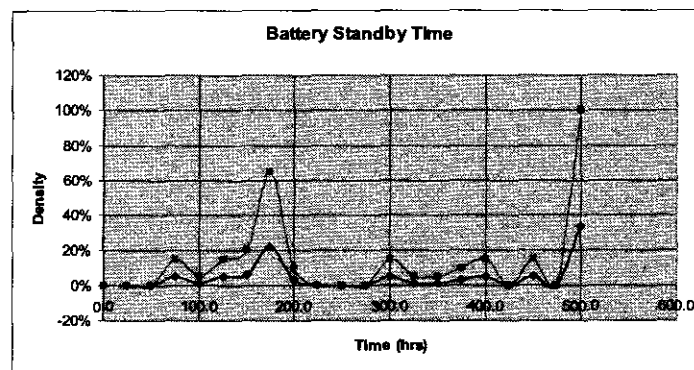


Figure E-23: Battery standby time – Probability density plot

Boundary 1: time = 500 hrs at 100 %

Boundary 2: time = 162.5 hrs at 60%

Boundary 1 / 3 = 166.7 hrs

Thus boundary 2 = $166.7 - [(166.7) - (162.5)] / 2$
 $= 164.6$ hrs

Boundary 3: time = 62.5 min at 10%

Boundary 2 / 3 = 54.9 hrs

Thus boundary 3 = 62.5 hrs

Table E-30: Battery standby time - Scoring boundaries

Open time	score
time $\leq$ 62.5 hrs	0
62.5 hrs $\leq$ time $\leq$ 164.6 hrs	0.15
164.6 hrs $\leq$ time $\leq$ 500 hrs	0.35
500 hrs $\leq$ time	0.5

E.5.3 Recharge ability

E.5.3.1 Criteria definition

The “*Recharge ability*” is the criterion in which one looks at the ability of the field units to recharge in an “out of office” environment (e.g. in a vehicle).



E.5.3.2 Criteria parameters/scoring determination

Table E-31: Short range communication connection time - Scoring boundaries

Recharge ability	score
yes	1.00
no	0.00

It is important that a field unit is able to be recharged in the field situation if the unit operator forgot to charge the unit beforehand or if some type of problem with the power occurred. Thus, if it is not possible for the field to recharge the unit will get a "0" score.

E.5.4 Battery charge time (office)

E.5.4.1 Criteria definition

The "battery charge time" is the time required by the field unit to be fully charged from a completely depleted battery up to the moment the battery is fully charged. In this criterion the field unit is charged in an indoor/office environment where 220v is available.

E.5.4.2 Criteria parameters/scoring determination

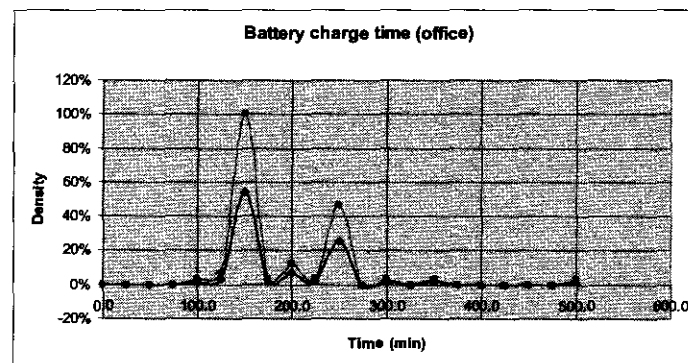


Figure E-24: Battery charge time (office) – Probability density plot

Boundary 1: time = 150 min at 100 %

Boundary 2: time = 160 min at 60%

$3 * \text{boundary 1} = 450 \text{ min}$

Thus boundary 2 = 160 min



Boundary 3: time = 270 min at 10%

$$3 * \text{boundary 2} = 370 \text{ min}$$

$$\begin{aligned} \text{Thus boundary 3} &= 160 + [(370) - (160)]/2 \\ &= 265 \text{ min} \end{aligned}$$

Table E-32: Battery charge time (office) – Scoring boundaries

Open time	score
time $\leq$ 150 min	0.5
150 min $\leq$ time $\leq$ 160 min	0.35
160 min $\leq$ time $\leq$ 265 min	0.15
265 min $\leq$ time	0

E.5.5 Battery charge time (mobile/car)

E.5.5.1 Criteria definition

The “battery charge time” is the time required by the field unit to be fully charged from a completely depleted battery up to the moment the battery is fully charged. In this criterion the field unit is charged in an outdoor environment where 12v (cigarette lighter in vehicle) is available.

E.5.5.2 Criteria parameters/scoring determination

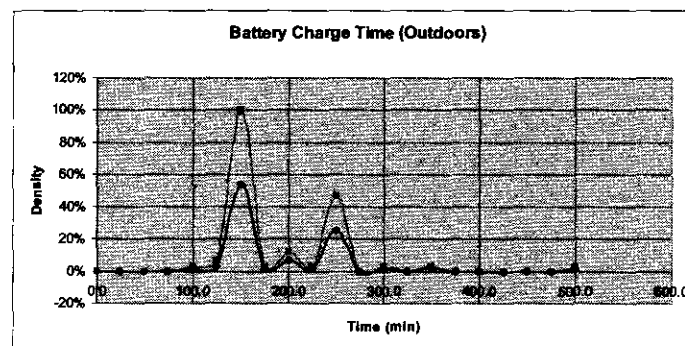


Figure E-25: Battery charge time (outdoors/mobile) – Probability density plot



Boundary 1: time = 150 min at 100 %

Boundary 2: time = 160 min at 60%

$$3 * \text{boundary 1} = 450 \text{ min}$$

$$\text{Thus boundary 2} = 160 \text{ min}$$

Boundary 3: time = 270 min at 10%

$$3 * \text{boundary 2} = 370 \text{ min}$$

$$\begin{aligned} \text{Thus boundary 3} &= 160 + [(370) - (160)] / 2 \\ &= 265 \text{ min} \end{aligned}$$

Table E-33: Battery charge time (outdoors/mobile) – Scoring boundaries

Open time	score
time $\leq$ 150 min	0.5
150 min $\leq$ time $\leq$ 160 min	0.35
160 min $\leq$ time $\leq$ 265 min	0.15
265 min $\leq$ time	0

E.5.6 Physical robustness

E.5.6.1 Criteria definition

The “*Physical robustness*” criterion of the field unit consists of three sub-criteria, to which a field unit could comply. The three sub-criteria are: electric shock, water-splash and physical shock resistance.

E.5.6.2 Criteria parameters/scoring determination

This criterion's scoring boundaries are determined opposite to the example given because in this criterion, the more sub criteria the unit is resistant to, the better the score.



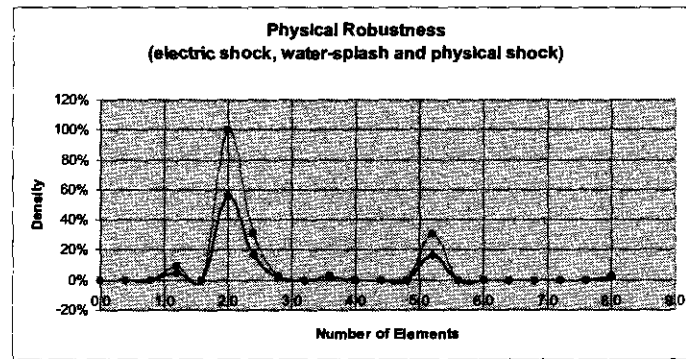


Figure E-26: Physical robustness – Probability density plot

Table E-34: Physical robustness - Scoring guideline

Sub criteria	Score for Figure E-26 (above)
elec & splash & shock resistant	6
splash & shock resistant	5
elec & splash resistant	4
elec & shock resistant	3
splash resistant	2
shock resistant	2
elec resistant	1

Boundary 1: time = 2 criteria at 100 %

Boundary 2: time = 2.2 criteria at 60%

3 * boundary 1 = 3 criteria

Thus boundary 2 = 3 criteria

Boundary 3: time = 5.5 criteria s at 10%

3 * boundary 2 = 9 criteria

Thus boundary 3 = 6 s

Table E-35: Physical robustness - Scoring boundaries

Criteria boundaries	score
criteria < 2	0
$2 \leq \text{criteria} < 3$	0.25
$3 \leq \text{criteria} < 6$	0.35
$6 \leq \text{criteria}$	0.5



E.5.7 Physical weight

E.5.7.1 Criteria definition

The “Physical weight” criterion of the field unit merely compares the different field units with respect to their mass (in gram). The field unit that is the lightest will score the highest because it would make the field unit easier to move around and use outdoors.

E.5.7.2 Criteria parameters/scoring determination

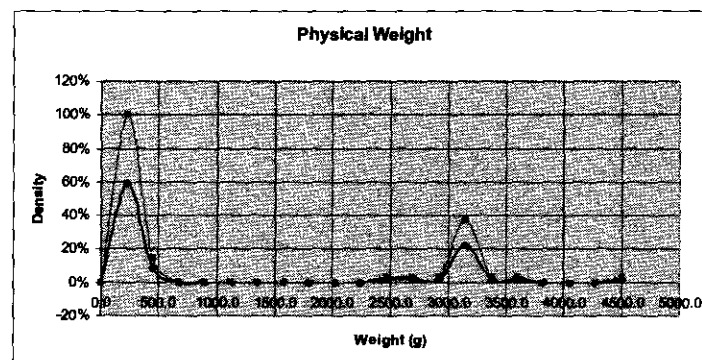


Figure E-27: Physical weight – Probability density plot

Boundary 1: time = 200 g at 100 %

Boundary 2: time = 350 g at 60%

$$3 * \text{boundary 1} = 600 \text{ g}$$

$$\text{Thus boundary 2} = 350 \text{ g}$$

Boundary 3: time = 3300 g at 10%

$$3 * \text{boundary 2} = 1050 \text{ g}$$

$$\begin{aligned} \text{Thus boundary 3} &= 1050 + [(3300)-(1050)]/2 \\ &= 2175 \text{ g} \end{aligned}$$

Table E-36: Physical weight - Scoring boundaries

Criteria boundaries	score
mass $\leq$ 200 g	0.5
200 g $\leq$ mass $\leq$ 350 g	0.35
350 g $\leq$ mass $\leq$ 2175 g	0.15
2175 g $\leq$ mass	0



E.5.8 Physical size

E.5.8.1 Criteria definition

The “*Physical Dimensions/Volume*” criterion of the field unit merely compares the different field units with respect to their size (measured in volume). The field unit that is the smallest will score the highest because it would make the field unit easier to move around and to use outdoors.

E.5.8.2 Criteria parameters/scoring determination

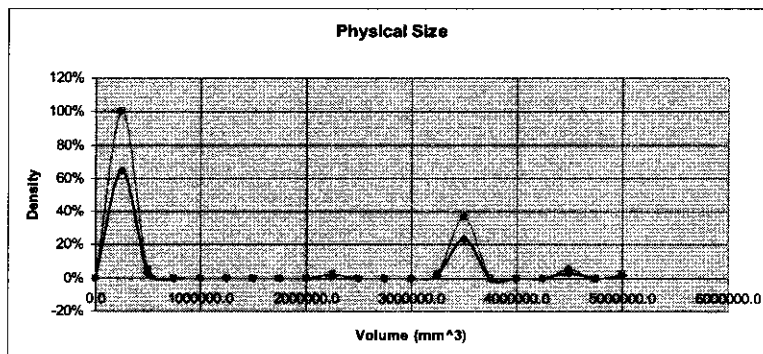


Figure E-29: Physical weight – Probability density plot

Boundary 1: time = 250 000 mm³ at 100 %

Boundary 2: time = 350 000 mm³ at 60%

$$3 * \text{boundary 1} = 750\,000 \text{ mm}^3$$

$$\text{Thus boundary 2} = 350\,000 \text{ mm}^3$$

Boundary 3: time = 3 500 000 mm³ at 10%

$$3 * \text{boundary 2} = 1\,050\,000 \text{ mm}^3$$

$$\begin{aligned} \text{Thus boundary 3} &= 1\,050\,000 + [(3\,500\,000) - (1\,050\,000)]/2 \\ &= 2\,175\,000 \text{ mm}^3 \end{aligned}$$

Table E-37: Physical weight - Scoring boundaries

Open time	score
volume $\leq$ 250 000 mm ³	0.5
250 000 mm ³ $\leq$ volume $\leq$ 350 000 mm ³	0.35
350 000 mm ³ $\leq$ volume $\leq$ 2 175 000 mm ³	0.15
2 175 000 mm ³ $\leq$ volume	0



E.6 Cost: Initial Cost

- Unit purchase: The cost incurred when buying the unit (this includes additional cabling and docking stations).
- User training cost: The cost incurred for training the field operators to use the field units.
- Unit operating system cost: The cost incurred for purchasing the Operating System (OS) if it is not included in the "*Unit purchase*" cost.
- GPRS software cost: The cost incurred for purchasing the software that is needed to operate the GPRS connection if it is not included in the OS.
- Short range communication software cost: The cost incurred for purchasing the software that is needed to operate the short range communication connection if it is not included in the OS.

E.7 Cost: Connection Cost

- Initial GPRS connection cost: The cost incurred for the initial connection to the GPRS network.
- Initial short range communication connection cost: The cost incurred for the initial connection for the "*Short range communication connection*".

E.8 Cost: Usage Cost

- GPRS monthly average usage cost: The cost incurred for the monthly subscription for the GPRS connection.
- Short range average usage cost: The cost incurred for the monthly subscription for the "*Short range communication connection*".
- GPRS monthly average subscription: The cost incurred for the average connection usage per month.



- Short range monthly average subscription: The cost incurred for the average connection usage per month.

E.9 Conclusion

In this appendix steps 4 and 5 of the MCDA model that were discussed in chapter 4 were explained. It covered the complete description of how the scale boundaries were determined. It also gave a complete definition of each criterion, what is meant by it and how it is measured.



Appendix F : Sensitivity Analyses

F.1 MCDA Single Criteria Sensitivity (on final score)

In the following few sections the focus will be on these criteria by plotting the changes in the final score while changing the weights of the individual criteria consecutively.

F.1.1 Specification

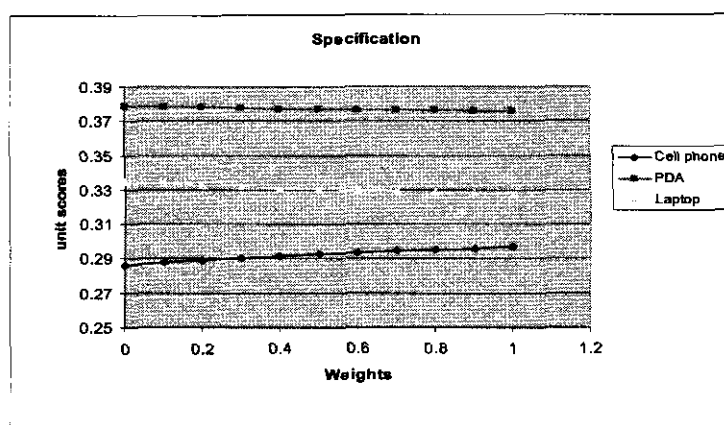


Figure F-1: Change final score caused by the Specification criterion weights changes

By observing the changes that occur in Figure F-1 one finds that the PDA does not really show any changes. On the other hand, while the Laptop's score decreases the Cell Phone's score increases. The increase

and decrease is not enough to cause a change in the ranking order of the field units and should not be identified as a big problem. Thus the weight of this criterion is not of the utmost importance.

F.1.2 Processing Capability

By observing the changes that occur in Figure F-2 one can see that the PDA does not really show any changes. On the other hand, while the Laptop's score increases the Cell Phone's score decreases. The increase and decrease is enough to cause a change in the ranking order of the field units and should be identified as a sensitive criterion.



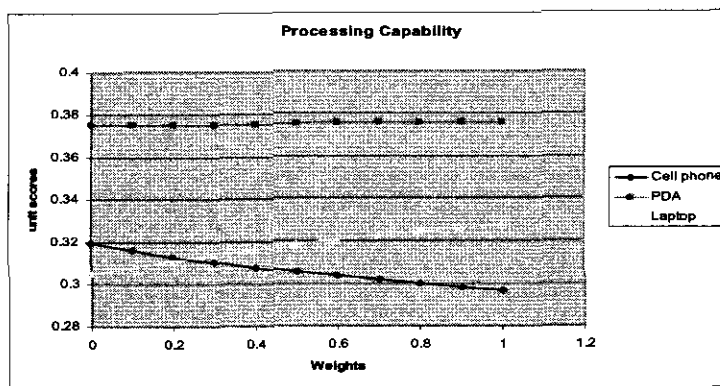


Figure F-2: Change final score caused by the Process Capability criterion weights changes

The weights of this criterion should be selected carefully. The crossing point of the Cell Phone and the Laptop is at weight = 0.25

F.1.3 Connection Capability

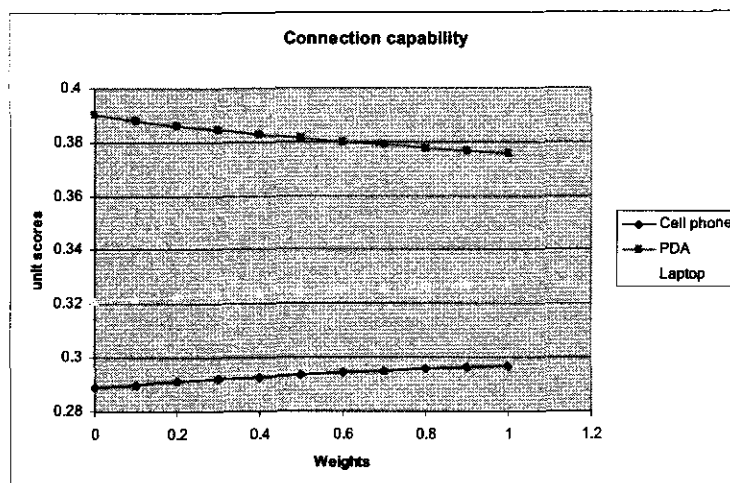


Figure F-3: Change final score caused by the Connection Capability criterion weights changes

By observing the changes that occur in Figure F-3 one finds that the PDA's score decreases while Laptop and Cell Phone's score increase. The increases and decrease is not enough to cause a change the in ranking order of the field units but should be identified as a sensitive criterion.

Portability

Observing the changes that occur in Figure F-4 one finds that the PDA and Cell Phone's scores increase while the Laptop's score decreases (Laptop's weak criterion). The increases and decrease are not enough to cause a change in the ranking order of the field units but they affect all of the field units and could cause a change in the rank of the field units (if another criteria should show the same characteristics). This



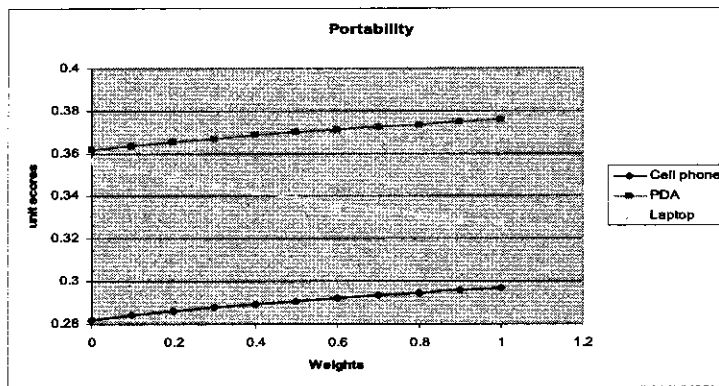


Figure F-4: Change final score caused by the Portability criterion weights changes

should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the ranking of the field units (if other criteria should show the same characteristics).

F.1.4 Cost

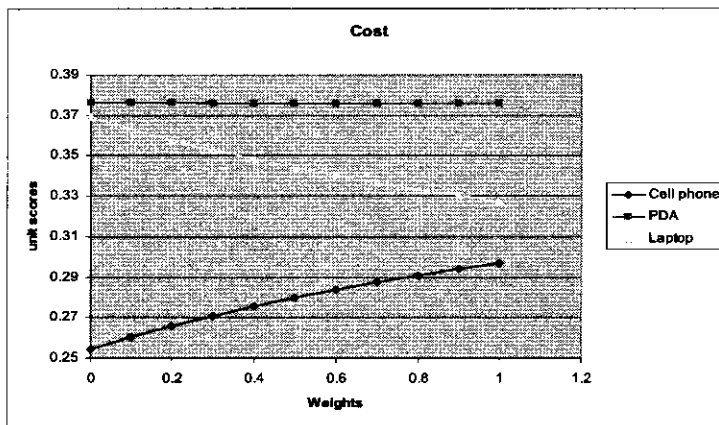


Figure F-5: Change final score caused by the Cost criterion weights changes

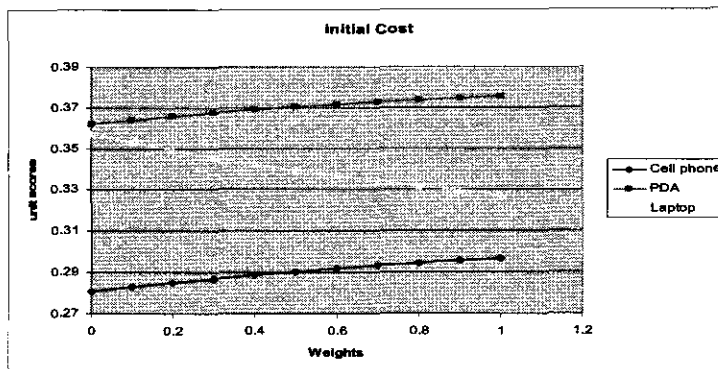
By observing the changes that occur in Figure F-5 one finds that the PDA does not really show any changes. On the other hand, while Laptop's score decreases, the Cell Phone's score increases (Cell Phone's strong criterion and Laptop's weak criterion).

The increase and decrease is not enough to cause a change in the ranking order of the field units, but should be identified as a sensitive criterion. It could cause a change in the ranking of the field units (if other criteria should show the same characteristics).

By observing the changes that occur in Figure F-6 one finds that the PDA and Cell Phone's scores increase while the Laptop's score decreases (Laptop's weak criterion). The increases and decrease are not enough to cause a change in the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria



F.1.5 Initial Cost



should show the same characteristics).

Figure F-6: Change final score caused by the Initial Cost criterion weights changes

F.1.6 Connection Cost

By observing the changes that occur in Figure 5-37 one finds that the PDA and Cell Phone's scores decrease while the Laptop's score increases. The increases and decrease are not enough to cause a change in rank order of the field units but should

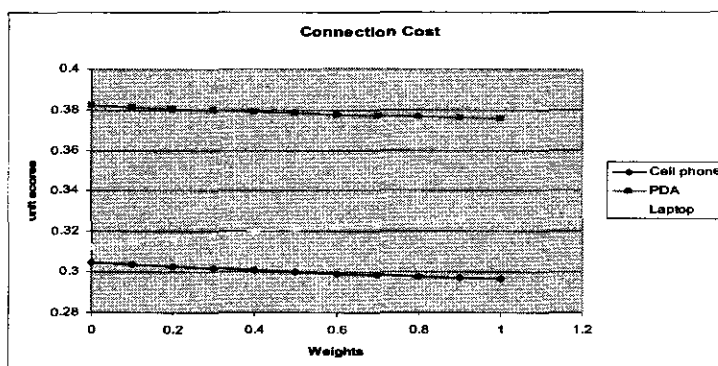


Figure F-7: Change final score caused by the Connection Cost criterion weights changes

be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics). The

connection score of the three field units is precisely the same and the reason why it makes a change in the final score is because it tries to equal out the scores.

F.1.7 Usage cost

By observing the changes that occur in Figure F-8 one finds that the PDA and Cell Phone's scores decrease while the Laptop's score increases. The increases and



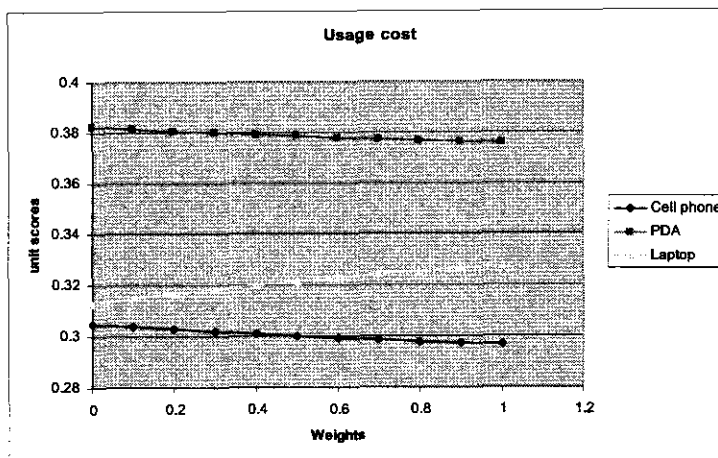


Figure F-8: Change final score caused by the Usage Cost criterion weights changes

decrease are not enough to cause a change in the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics). The connection score of the three field units is precisely the same and the reason way it makes a change in the final score is because it tries to equal out the scores.

F.1.8 Usability

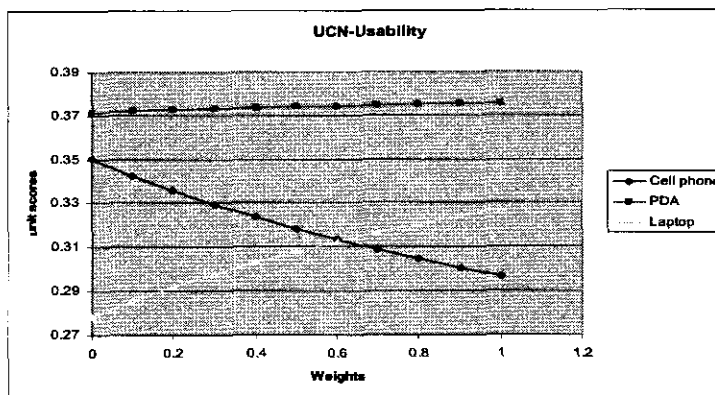


Figure F-9: Change final score caused by the Usability (UCN) criterion weights changes

By observing the changes that occur in Figure F-9 one finds that the PDA does not really show any changes. On the other hand, while Laptop's score increases the Cell Phone's score decreases. The increase and decrease is enough to cause a change in the ranking order of the field units and should be identified as a sensitive criterion. The weights of this criterion should be selected carefully. The crossing point of the Cell Phone and the Laptop is at weight = 0.6

decrease are not enough to cause a change in the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria

By observing the changes that occur in Figure F-9 one finds that the PDA does not really show any changes. On the other hand, while Laptop's score increases the Cell Phone's score decreases. The increase



F.2 Conclusion MCDA Single Criteria Sensitivity (on final score)

In the section above the focus was on the effects the changes of the weights had on the score of the field units in terms of the changes they make in the final scores. In Figure 5-36 one can see the comparison of the different criteria with their changes displayed. One notices that the criteria that are sensitive to changes and carry a big weight in the evaluation model had higher values in Figure 5-36. Thus by comparing the minimum and maximum of each criterion one can conclude that the higher the level of the criteria the bigger the impact the unit has on the evaluation model.

By focusing on Figure F-1 to Figure F-9 one observes that the PDA seems to be the most stable field unit for this case study. This is concluded from the fact that in most of the figures studied the PDA's score changes the least, making it the least sensitive unit to changes of criteria weights for this type of sensitivity analysis.

F.3 MCDA Single Criteria Sensitivity (on "one level up" score)

In the follow few sections the focus will be on these criteria by plotting the changes in the "one level up" score while changing the weights of the individual criteria consecutively.

F.3.1 Specification

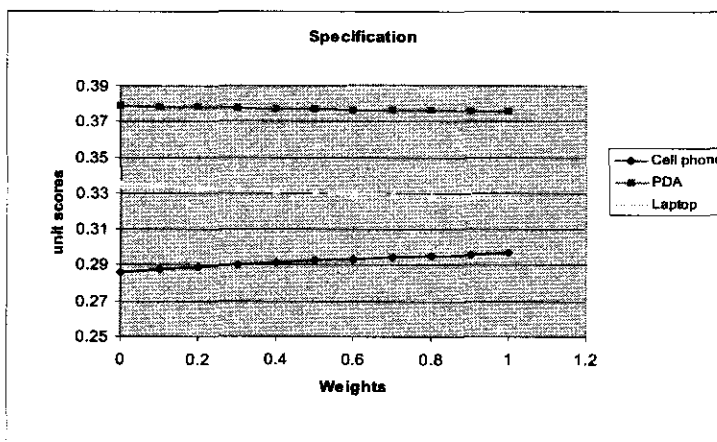


Figure F-10: Change final score caused by the Specification criterion weights changes

By observing the changes that occur in Figure F-10 one find that the PDA does not really show any changes. On the other hand, while the Laptop's score decreases the Cell Phones score increases. The increase

and decrease is not enough to cause a change in the ranking order.



F.3.2 Processing Capability

By observing the changes that occur in Figure F-11 one finds that the PDA does not really show any changes. On the other hand, while the Laptop's score increases the Cell Phone's score decreases. The increase and decrease is enough to cause a change in the ranking order of the field units and should be identified as a sensitive criterion. The change in rank (between PDA and Cell Phone) occurs at Weight = 0.2

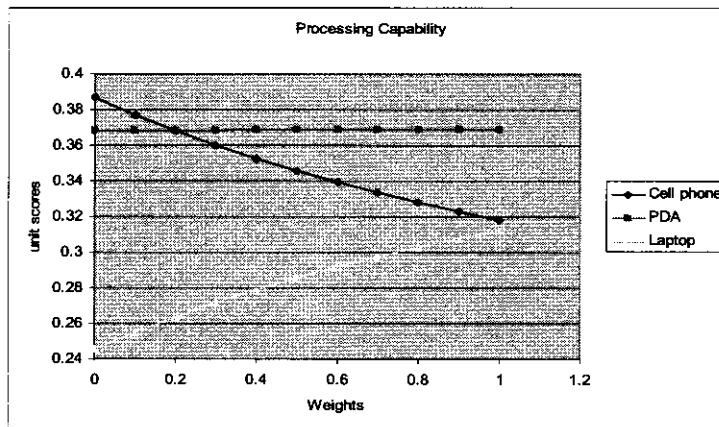


Figure F-11: Change specification score caused by the Process Capability criterion weights changes

(a crossing between Cell Phone and Laptop also almost occurs at weight = 1). The weights of this criterion should be selected carefully (these criteria seem to be very sensitive to changes).

F.3.3 File Compression Availability

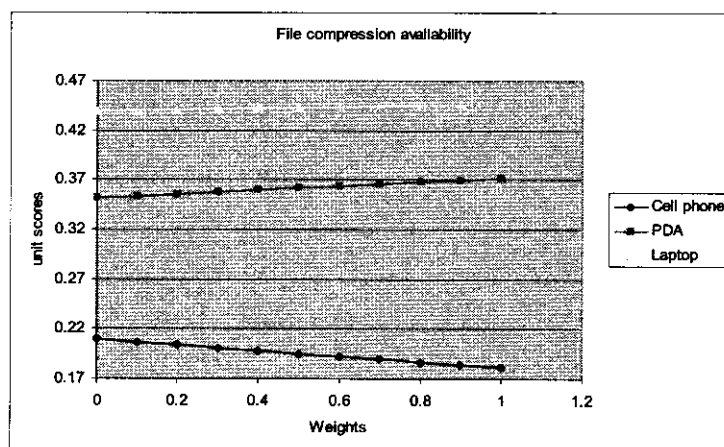


Figure F-12: Change Process Capability score caused by the Compression Availability criterion weights changes

By observing the changes that occur in Figure F-12 one finds that the PDA and Laptop's score increases (Laptop and PDA's strong criterion) while the Cell Phone score decreases (this can be expected because most Cell

Phones do not yet support file compression capabilities). The increases and decrease are not enough to cause a change in rank order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could



cause a change in the rank of the field units (if other criteria should show the same characteristics).

F.3.4 Application switching

By observing the changes that occur in Figure F-13 one finds that the PDA and Laptop's score increases (Laptop and PDA's strong criterion) while the Cell Phone score decreases (this can be expected because most Cell Phones do not support application switching capabilities yet). The increases and decrease are not

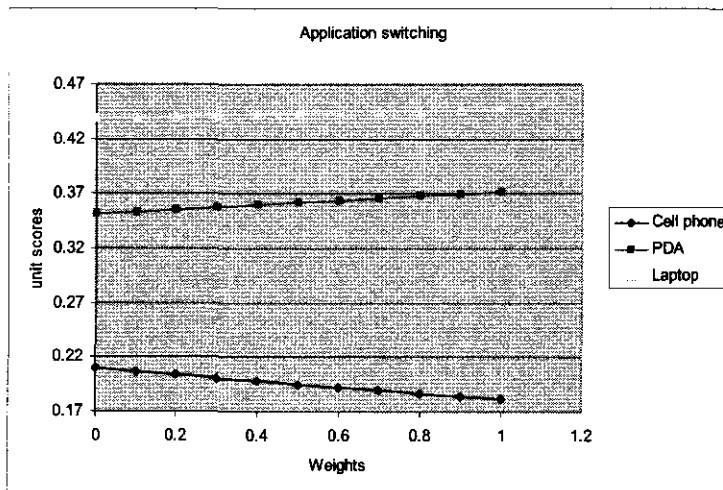


Figure F-13: Change Process Capability score caused by the Application Switching criterion weights changes

enough to cause a change in the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics).

Connection Capability

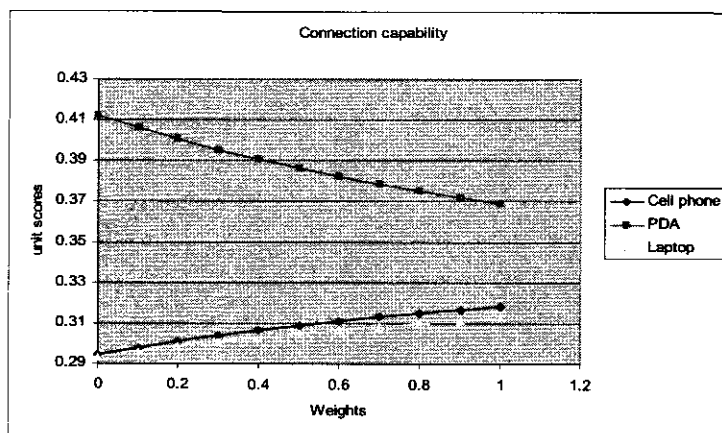


Figure F-14: Change Specification score caused by the Connection Capability criterion weights changes

By observing the changes that occur in Figure F-14 one find that the Laptop and Cell Phone's score increase (Laptop and Cell Phone's strong criterion) while the PDA's score decreases (this can be expected



because the Laptop and Cell Phone's scores are pulled up by the falling score of the PDA). The increases and decrease are not enough to cause a change in rank order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics).

F.3.5 GPRS connection time

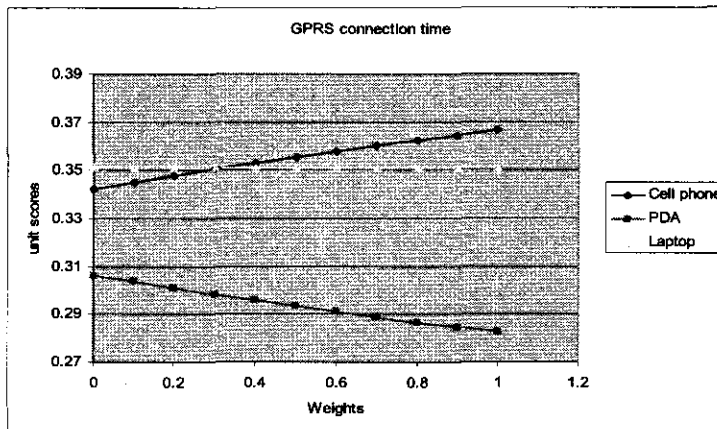


Figure F-15: Change Connection Capability score caused by the Process Capability criterion weights changes

By observing the changes that occur in Figure F-15 one finds that the Laptop does not really show any changes. On the other hand, while Cell Phone's score increases the PDA's score decreases. The increase and decrease

is enough to cause a change in the ranking order of the field units and should be identified as a sensitive criterion. The change in rank (between Laptop and Cell Phone) occurs at Weight = 0.3. For the majority of the weights tested the Cell phone has the highest score making it the better unit where Connection Capability is of importance. The weights of this criterion should be selected carefully (this criteria seems to be very sensitive to changes).

F.3.6 Short range communication availability

By observing the changes that occur in Figure F-16 one finds that the PDA does not really show any changes. On the other hand while the Laptop's score increases the Cell Phone's score decreases. The increase and decrease is not enough to cause a change in the ranking order of the field units, but should be identified as a sensitive criterion. The weights of this criterion must be selected carefully.



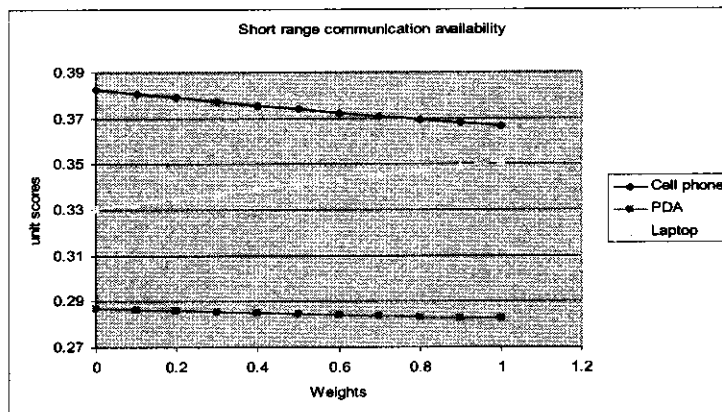


Figure F-16: Change Connection Capability score caused by the Process Capability criterion weights changes

F.3.7 Short range communication connection time

By observing the changes that occur in Figure F-17 one finds that the Laptop does not really show any changes. On the other hand while Cell Phone's score increases the

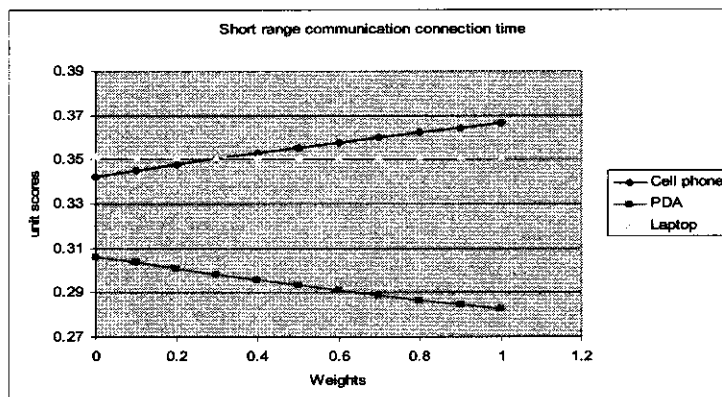


Figure F-17: Change Connection Capability score caused by the Process Capability criterion weights changes

PDA's score decreases. The increase and decrease is enough to cause a change in rank order of the field units and should be identified as a sensitive criterion. The change in rank (between Laptop and Cell Phone)

occurs at Weight = 0.3. For the majority of the weights tested the Cell Phone has the highest score making it the better unit where Connection Capability is of importance. The weights of this criterion should be selected carefully (this criteria seems to be very sensitive to changes).

F.3.8 Short range communication Connection speed

By observing the changes that occur in Figure F-18 one can find that the Laptop and Cell Phone's scores decrease (Laptop and Cell Phone's weak criterion) while the



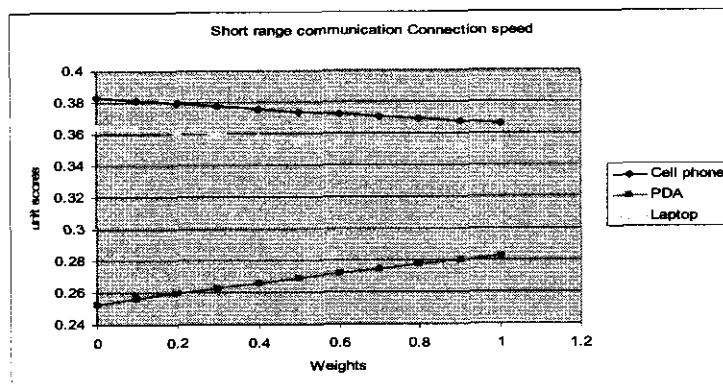


Figure F-18: Change Connection Capability score caused by the Process Capability criterion weights changes

the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics).

F.3.9 Portability

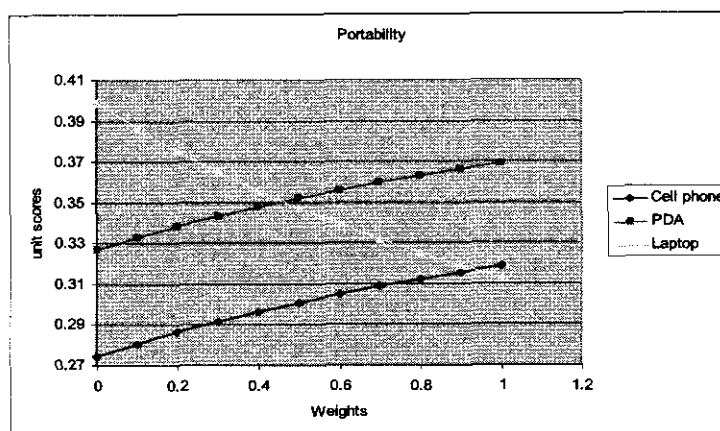


Figure F-19: Change Specification score caused by the Portability criterion weights changes

a change in the ranking order of the field units (two times) and should be identified as a "very" sensitive criterion. The change in rank between PDA and Laptop occurs at Weight = 0.475 and the crossing between Cell Phone and Laptop occurs at weight = 0.925. The weights of this criterion should be selected "very" carefully (this criteria seem to be "very" sensitive to changes in its weights).

PDA's score increases (this can be expected because the Laptop and Cell Phone's scores are pulled down by the rising score of the PDA). The increases and decrease are not enough to cause a change in

By observing the changes that occur in Figure F-19 one finds that the PDA and Cell Phone's scores increase while the Laptop's score decreases (Laptop's weak criterion). The increase and decrease are enough to cause



F.3.10 Recharge ability

By observing the changes that occur in Figure F-20 one finds that the PDA and Cell Phone's scores increase (Laptop and Cell Phone's strong criterion) while the Laptop's score decreases (this can be expected because the PDA and Cell Phone's scores are pulled up by the falling score of the Laptop). The increases and decrease are not enough to cause a change in the ranking order of the field units but should

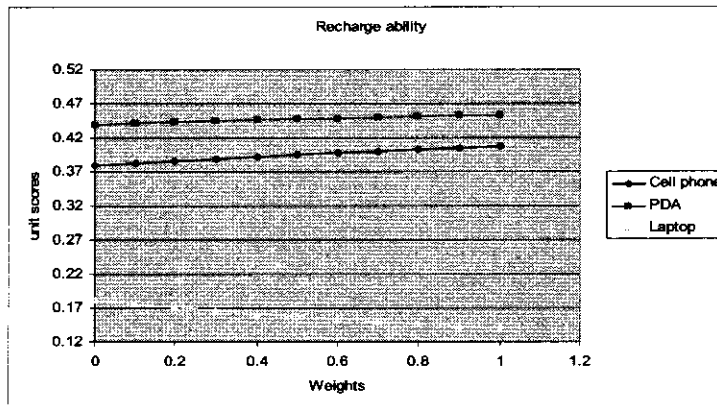


Figure F-20: Change Portability score caused by the Process Capability criterion weights changes

be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics).

F.3.11 Cost

By observing the changes that occur in Figure F-21 one finds that the PDA does not really show any changes. On the other hand, while the Laptop's score decreases the Cell Phone's score increases (Cell Phone's strong Criterion and Laptop's weak criterion). The increase and decrease is not enough to cause a change in the

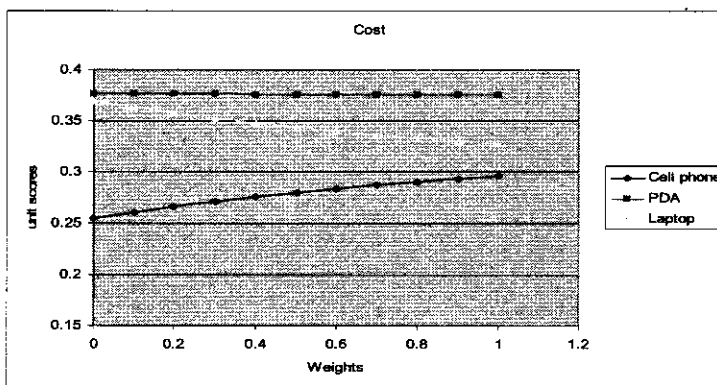


Figure F-21: Change final score caused by the Cost criterion weights changes

ranking order of the field units, but should be identified as a sensitive criterion. It could cause a change in the rank of the field units (if other criteria should show the same characteristics).



F.3.12 Initial Cost

By observing the changes that occur in figure F-22 one finds that the PDA and Cell Phone's scores increase while the Laptop's score decreases (Laptop's weak criterion). The increases and decrease are not enough to cause a change in rank order of

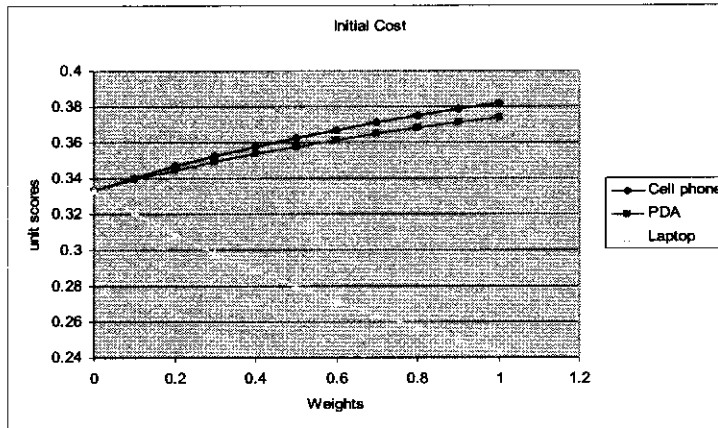


Figure F-22: Change final score caused by the Initial Cost criterion weights changes

the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the same characteristics).

Connection Cost

By observing the changes that occur in Figure F-23 one finds that the PDA and Cell Phone's scores decrease while the Laptop's score increases. The increases and

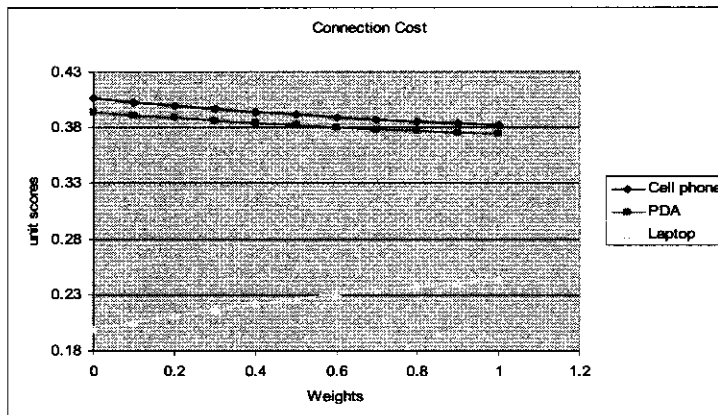


Figure F-23: Change Cost score caused by the Connection Cost criterion weights changes

decrease are not enough to cause a change in rank order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria

should show the same characteristics). The connection score of the three field units is precisely the same and the reason why it makes a change in the final score is because it tries to equal out the scores.



F.3.13 Usage cost

By observing the changes that occur in Figure F-24 one finds that the PDA and Cell Phone's scores decrease while the Laptop's score increases. The increases and decrease are not enough to cause a change in the ranking order of the field units but should be identified as a sensitive criterion because it affects all of the field units and could cause a change in the rank of the field units (if other criteria should show the

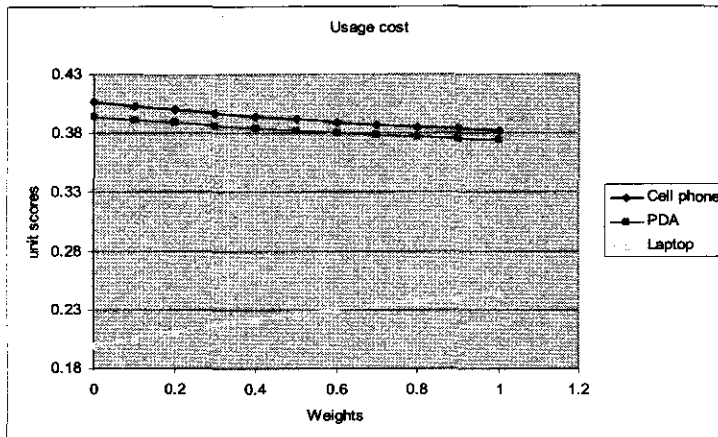


Figure F-24: Change Cost score caused by the Usage Cost criterion weights changes

same characteristics).

The connection score of the three field units is precisely the same and the reason why it makes a change in the final score is because it tries to equal out the scores.

F.3.14 Usability

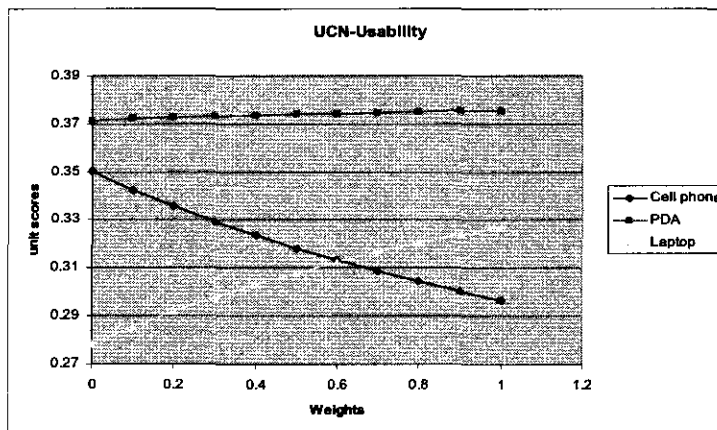


Figure F-25: Change final score caused by the Usability (UCN) criterion weights changes

By observing the changes that occur in Figure F-25 one finds that the PDA does not really show any changes. On the other hand, while Laptop's score increases the Cell Phone's score decreases. The increase and decrease

is enough to cause a change in the ranking order of the field units and should be identified as a sensitive criterion. The weights of this criterion should be selected carefully. The crossing point of the Cell Phone and the Laptop is at weight = 0.6



F.4 Conclusion of MCDA Single Criteria Sensitivity (on one level up score)

In the section above the focus was on the effects the changes of the weights had on the score of the field units in terms of the changes they make in the “one level up” scores (“one level up” – meaning that if the weights of a level-2 criteria changes, a look at what changes in score it causes in its level-1 criteria). In Figure 5-41 one can see the comparison of the different criteria with their changes displayed. It was detected that the criteria that are sensitive for changes and carry a big weight in the evaluation model had higher values in Figure 5-41. In this section it is observed that the number of criteria that were affected on their “one level up” criteria are much more than those that were discussed in the previous section (the criteria that had a big affect on the final score).

By focusing on Figure F-10 to Figure F-25 it is observed that the PDA seems to be the most stable field unit for the case study. In contradiction with the previous sensitivity analyses (), the PDA does show some grade of sensitivity. Thus the PDA is less sensitive to changes in the weights than the Cell Phone and Laptop but should still be considered as sensitive in this sensitivity analyses.

