

https://dspace.org/

# Subconscious (tacit) structures of expertise: What goes on in the minds of Eskom network controllers as they work with a new computer interface.

**Lazanas, Panagiotis**

**2013-07-22**
http://hdl.handle.net/10539/12870

Downloaded from a DSpace repository. https://dspace.org/

# SUBCONSCIOUS (TACIT) STRUCTURES OF EXPERTISE:

## WHAT GOES ON IN THE MINDS OF ESKOM NETWORK CONTROLLERS AS THEY WORK WITH A NEW COMPUTER INTERFACE

Panagiotis Lazanas

A thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for the degree of Doctor of Philosophy.

Johannesburg, 2012

## Declaration

I declare that this thesis is my own unaided work. It is being submitted to the Degree of Doctor of Philosophy to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination to any other University.

……
(Signature of Candidate)

……..day of ……..year ……..
*day* *month* *year*

**Abstract:**

The Eskom electricity transmission grid controllers at the National Control Centre (NCC) in Germiston, South Africa, rely on their expertise, developed over years, in order to carry out their work. This expertise includes many skills rooted in subconscious processing and interactions. These tacit strategies and mental content have evolved in relation to the network data, presented to them by means of computer displays and other means (telephone, personal contact, etc.). This data is then converted to information about the network in their minds. The information is then processed subconsciously and consciously, so that the sophisticated interpretation algorithms, which have evolved in their minds, can identify the state of affairs in the network and prompt them to action. Two years ago (2008) a new computer interface was introduced at the NCC, which is Windows based, this new format is referred to as the TEMSE system. Data is now presented in a different format, with a slightly different appearance, and different configuration. This work aims to contribute to the body of knowledge pertaining to human controller performance factors, by identifying the impact of the implementation of the new displays on the tacit or subconscious mental processing of both expert and novice controllers. Simulator tasks and interviews were designed to elicit the tacit activity in the controllers' minds in response to the new TEMSE interface. A variation of Retrospective Verbal Protocol analysis was used during the interviews in order to elicit the tacit dimensions investigated, adapted for this purpose (by including Sub-modality Elicitation techniques, and Metamodel type questions from Neuro-Linguistic Programming (NLP)), referred to as the Tacit Retrospective Verbal Protocol analysis (TRVP). The findings show that the controllers' minds are influenced at various levels by the interface changeover. Extensive evidence of the presence of tacit imagery, auditory, and other complex emotive components within each controller is presented, which hitherto had remained unnoticed. Making these influences explicit can be the first step in structuring appropriate training and other interventions, in order to improve overall controller performance. An extensive list of recommendations proposes interventions to improve controller performance as well as computer interface design. Eskom network controllers are real experts in their work, with many years of naturalistic decision-making experience. Access to such subjects provided a true source of embedded tacit expertise.

## ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions made by each of his supervisors towards his understanding and appreciation of their respective fields. Many thanks to Professor Andrew Thatcher for enriching the author's understanding of Engineering and Cognitive Psychology and for his meticulous support. Much appreciation is due to Professor Ian Jandrell for facilitating the integration of the Engineering and Psychological aspects of the project. To Mr Jan Muller at the Eskom NCC, thanks for facilitating the author's exposure to the world of Power System Control and specifically for arranging all the interviews with the controllers, as well as for the support over the duration of the project in the NCC.

Similarly to Mr Jan Hofmayer also at the NCC. The author would also like to acknowledge the contribution made by Eskom, towards the funding of the project, without whose support this research would never have taken place. Finally I wish to thank each and every one of the controllers who gave of their time in order to make this project a success.

# ACRONYMS AND SYMBOLS

**ATC** Available Transmission Capacity

**CC** Control Centre

**CFL** Compact Fluorescent Lamps

**CGUI** Character Graphics User Interface

**CP** Cognitive Psychology

**CRM** Crew Resource Management

**EMS** Energy Management System

**EPRI** Electrical Power Research Institute

**FGUI** Full Graphics User Interface

**HMI** Human Machine Interface

**LMP** Locational Marginal Price

**NQF** National Qualifications Framework

**NCC** National Control Centre

**NDM** Naturalistic Decision Making

**OPF** Optimal Power Flow

**PDP** Parallel Distributed Processing

**PP** Primary Plant

**PSAT** Power System Analysis Tool

**PTDF** Power Transfer Distribution Factors

**RPDM** Recognition-Primed Decision-Making model

**RVP** Retrospective Verbal Protocol

**SAPP** Southern African Power Pool

**SP** Secondary Plant

**STM** Short Term Memory

**SVC** Static VAR Compensator

**TAV** Task Adaptive Visualization

**TRVP** Tacit Retrospective Verbal Protocol

**UI** User Interface

**VPA** Verbal Protocol Analysis

# TABLE OF CONTENTS


| **Contents** | | **Page** |
|---|---|---|
| **Abstract:** | | **iii** |
| **ACKNOWLEDGEMENTS** | | **iv** |
| **ACRONYMS AND SYMBOLS** | | **v** |
| **LIST OF TABLES** | | **xi** |
| **CHAPTER 1: INTRODUCTION** | | **1** |
| 1.1 | Background | 1 |
| 1.2 | The Controllers | 3 |
| 1.3 | The New Working Conditions | 3 |
| 1.4 | The Investigation | 5 |
| 1.5 | The Theoretical Background | 6 |
| 1.6 | The Scope of the Research | 9 |
| 1.7 | The Research Contribution | 10 |
| 1.8 | Chapters | 10 |
| | Chapter 2: Background | 10 |
| | Chapter 3: Methods Used | 11 |
| | Chapter 4: Results | 12 |
| | Consolidated Results | 12 |
| | Chapter 5: Discussion, Recommendations, and Conclusion | 13 |
| Appendix A: | Controller written reports and sketches | 13 |
| Appendix B: | Controller forms of the second question on emotions | 13 |
| Appendix C: | TEMSE and ENCOR screen images | 13 |
| Appendix D: | Extended results section | 13 |
| **CHAPTER 2: BACKGROUND** | | **15** |
| 2.1 | Chapter Sections | 15 |
| 2.2 | The Problem Statement | 16 |
| 2.3 | Aim | 16 |
| 2.4 | The Research Hypothesis | 17 |
| 2.5 | General Considerations | 18 |

| | | |
|---|---|---|
| 2.6 | The Tacit Domain and Qualia | 19 |
| 2.7 | Findings from the Literature Review and Discussion of the Assumptions and Limitations of Existing Knowledge | 22 |
| 2.7.1 | Aims of the Review | 22 |
| | A. The field dealing with Power System control, and HMI display design. | 25 |
| | B. The field of mental processing and the tacit domain from Cognitive Psychology | 26 |
| | C. The field of Industrial Psychology and Cognitive Ergonomics for the elicitation of Retrospective Verbal Protocols in particular | 27 |
| | D. The field of Neuro-Linguistic Programming (NLP) for elicitation techniques pertaining to the tacit domain | 27 |
| 2.8 | Review of the Field of Power System Visualization | 28 |
| 2.8.1 | Power System Elements | 28 |
| 2.8.2 | Power System Phenomena | 29 |
| 2.8.3 | Development of Energy Management Centres | 31 |
| 2.8.4 | Response Times and Requirements of Energy Management HMIs | 34 |
| 2.8.5 | Stress | 38 |
| 2.8.6 | HMI Design | 39 |
| 2.9 | Review of the Cognitive Psychology and Emotions Theory Fields. | 49 |
| 2.9.1 | Cognition and the Tacit Domain | 49 |
| 2.9.2 | Mental Models | 59 |
| 2.9.3 | Emotions | 61 |
| 2.9.4 | Qualia | 67 |
| 2.9.5 | Conscious Processing Delays | 70 |
| 2.9.6 | Naturalistic Decision Making | 71 |
| 2.10 | Knowledge Elicitation Techniques: Retrospective Verbal Protocol Analysis (RVPA). | 73 |
| 2.10.1 | Background | 73 |
| 2.10.2 | Methods of Elicitation | 81 |
| 2.10.3 | Retrospective Verbal Protocols | 88 |

2.10.4 Tacit Retrospective Verbal Protocol Analysis (TRVP) 91
2.11 Review of the Neuro-Linguistic Programming (NLP) Field 92
2.11.1 The Modelling Process 93
2.11.2 Logical Levels of mental processing 97
2.11.3 Sorting Styles (or filters) 99
2.11.4 Metaphors 99
2.11.5 Metamodel 100
2.11.6 Sub-modalities 103
2.11.7 Strategies 105
2.11.8 Body Language 106
2.11.9 Emotions 107
2.11.10 Other Elements 107
2.12 The Research Question 108
**CHAPTER 3: METHODS 111**
3.1 Chapter Content 111
3.2 Introduction 112
3.3 The Steps Taken to Conduct the Research 112
3.4 The List of Participants 117
3.5 Overall Impression of Participants 119
3.6 The Network Simulator Exercise Details 121
3.7 The TRVP Procedure: What Was Elicited, and Methods Used 123
3.8 The Methods of Analysis 130
3.8.1 Analysis of what they wrote 130
3.8.2 Analysis of the findings of the Emotions section 130
3.8.3 Analysis of the findings from the section on Tacit Content 131
3.8.4 Analysis of the findings of the section on Tacit Structures 132
3.8.5 Analysis of the findings from the Adjustments section 134
3.8.6 Analysis of the findings from the section Other Factors 134
3.8.7 Analysis of the findings from the Was This Useful section 135

| | | |
|---|---|---|
| 3.9 | Equipment Used | 135 |
| 3.10 | Ethics | 136 |
| 3.10.1 | Anonymity | 136 |
| 3.10.2 | Participation | 137 |
| 3.10.3 | Confidentiality | 137 |
| 3.10.4 | Feedback | 137 |
| **CHAPTER 4: RESULTS** | | **138** |
| 4.1 | Introduction | 138 |
| 4.2 | Categories of Results | 139 |
| 4.3 | Consolidation of Findings | 141 |
| 4.3.1 | Written Feedback | 142 |
| 4.3.2 | How long it took to make the Transition to TEMSE | 142 |
| 4.3.3 | Emotions | 144 |
| 4.3.4 | Tacit Content: Images and auditory mental content | 146 |
| 4.3.5 | Tacit Structures | 148 |
| 4.3.6 | Attention flexibility or fixation | 149 |
| 4.3.7 | Zooming in and out mentally to view larger sections of the network | 150 |
| 4.3.8 | Inhibiting factors slowing down performance | 151 |
| 4.3.9 | Other important factors which enhance or inhibit performance | 151 |
| 4.3.10 | Value of this exercise as perceived by the controllers | 152 |
| **CHAPTER 5: DISCUSSION, RECOMMENDATIONS AND CONCLUSION.** | | **153** |
| 5.1 | Discussion | 153 |
| 5.1.1 | The process: Looking back, lessons learned, the duration, the phases, the results | 153 |
| 5.1.2 | The Results | 155 |
| 5.1.3 | Difficulties encountered | 156 |
| 5.1.4 | What could have been better? | 157 |
| 5.1.5 | Future work | 157 |
| 5.1.6 | The limitations of this research | 158 |
| 5.2 | Recommendations | 159 |

5.2.1 Controller Performance Enhancement 159
5.2.2 HMI Design 165
5.2.3 Management Related Issues 165
5.3 Conclusion 168
**REFERENCES 170**
**BIBLIOGRAPHY 176**
**APPENDIX A 179**
**APPENDIX B 202**
**APPENDIX C 217**
**APPENDIX D 223**
D.1 Written Feedback 223
D.1.1 Analysis 225
D.2 Emotions 226
D.2.1 Controller Statements 228
D.2.2 Summary 232
D.2.3 Analysis 234
D.3 Tacit Content 235
D.3.1 Controllers' Tacit Content Descriptions 237
D.3.2 Summary of Results 246
D.3.3 Analysis 246
D.4 Tacit Structures 249
D.4.1 Controllers' Tacit Structure Descriptions 250
D.4.2 Summary of Tacit Sequences 256
D.4.3 Analysis 257
D.4.4 Inhibiting Factors 259
D.5 Adjustments: From ENCOR to TEMSE 260
D.5.1 Summary of Results 261
D.5.2 Analysis of Results 264
D.6 Other Important Factors 267
D.6.1 Other Factors Sequence List 268

D.6.2 Important Factors Summary (Performance Enhancing) 269

D.6.3 Important Factors Summary (Performance Inhibiting) 270

D.7 Value 272

D.7.1 Analysis 275

## LIST OF TABLES

Table 2.7.1.A: Researchers who have contributed to the field of mental models research 23

Table 2.8.2.A: Power System Phenomena, available Power System Controls, and appropriate Simulation Tools 30

Table 2.8.6.A: Steps taken by a controller in order to extract high level information about a network 40

Table 2.8.6.B: Steps taken by a controller when information is presented in a graphical format 42

Table 2.9.1.A: Processing steps in the process of cognition 54

Table 2.10.1.A: Research Methodologies 75

Table 2.11.5.A Metamodel violations, questions, and benefits 102

Table 3.3.A: List of volunteer controllers with descriptive elements 117

Table 3.4.A: Overall impression of each of the participating controllers 120

Table D.1. A: Controllers written descriptions of the simulator events 224

Table D.1.1.A: Findings from the controllers' written descriptions of the simulator events 225

Table D.2.2.A: Findings summary from the emotions section 233

Table D.3.1.A: Controllers tacit content descriptions 237

Table D.3.2.A: Summary of findings from the tacit content section 246

Table D.4.1.A: Controllers' description of tacit structure sequences 250

Table D.4.2.A: Summary of tacit sequences extracted from the controllers' descriptions 256

Table D.5.1.A: Summary of controller comments about adaptation times 261

Table D.6.1.A: Performance Enhancing and Inhibiting factors 268

Table D.6.2.A: Summary of responses from the Performance Enhancing factors column 269

Table D.6.3.A: Summary of responses from the Performance Inhibiting factors column 270

# Chapter 1:

# INTRODUCTION

## 1.1 Background

In our day-to-day lives we only seem to notice the Power Grid when it is not working. This enormous entity remains invisible and taken for granted. Yet there is not a single aspect of our lives that would not come to a complete standstill if the grid were to stop functioning. The Eskom Power System Transmission Network in particular is one of the largest "machines" on earth, in terms of the amount of energy it converts and delivers on a daily basis (up to 42 GW). In spite of its size though, it remains quite invisible to most of us. In the continent of Africa there are a number of such Power System networks. One of these interconnected Power System networks is the Southern African Power Pool (SAPP).

The Southern African Power Pool comprises a number of countries each with their own utility. These utilities are:

| | |
|---|---|
| **SNEL** | **D R Congo** |
| **TANESCO** | **Tanzania** |
| **ESCOM** | **Malawi** |
| **ZESCO** | **Zambia** |
| **ENE** | **Angola** |
| **NAMPOWER** | **Namibia** |
| **BPC** | **Botswana** |
| **ZESA** | **Zimbabwe** |
| **EdM** | **Mozambique** |
| **SEB** | **Swaziland** |
| **Eskom** | **South Africa** |

**LEC Lesotho**

Of these, South Africa is the largest producer as well as the largest consumer of electrical energy on the whole of the African continent. The national utility, Eskom, has a Nominal Capacity of 42 GW. It has 336270 km of Power Lines (including DC lines), the highest operating voltage being 765 kV ac. It generates annual revenues of over R 32.8 billion, with total assets of over R 965 billion, 28938 employees, and serves more than 4 million customers over an area of 1,123,000 $km^2$. ESKOM produces 60% of Africa's electrical energy (85% fossil fuel, 5% nuclear and 10% other, generation). It is among the top ten largest utilities in the world (Candy 2010).

The transmission part of the Eskom network (equipment rated from 765 kV to 220 kV) includes over 9000 circuit breakers and links, 2100 bus-bars, 430 transformers and 150 sub-stations. All this equipment is under direct Eskom control at the National Control Centre (NCC), and is exposed to weather conditions that include high temperatures (over $40^0$C), snow, ice, gale-force winds, coastal corrosion, lightning storms (one of the highest levels in the world), and fires (Candy, 2010). As a result the network is quite vulnerable. Events arising out of all the above factors can lead to large-scale disruptions or contingencies. During such contingencies the human controllers of this highly complex grid have to ensure that electrical energy continues to flow from the points of generation (power stations) to consumers via the national grid, over vast areas. This type of work is made possible by means of computerised interfaces, or Human Machine Interfaces (HMIs), which depict and control all the equipment within the network.

When large-scale contingencies occur, the information generated is more than any person can consciously absorb within the time frame in which it is generated. A single serious incident that occurred in the Natal region in 2009 generated over 2670 alarms within five minutes (Muller, 2010). Further, the financial and various other consequences of such incidents are extremely high. The cost of partial or total blackouts is in the order of billions of rand. As an example, the 2003 blackouts in the eastern part of the USA and Canada, over just three days, were estimated by the USA Department of Energy (DOE) to

have cost $ 6 billion or over R40 billion (ELCON, 2004). According to NCC statistics during 2003 there were 84 blackouts across the world, in the USA, UK, Italy, Brazil, Australia, and Russia (Hofmayer, 2010).

## 1.2 The Controllers

In order to operate the Eskom transmission network the human controllers work in twelve-hour shifts at the National Control Centre (NCC) in Germiston, near Johannesburg. These controllers ensure that the SAPP and the Eskom Transmission grid in particular, perform their function on a moment-to-moment basis, within preset parameters, such as a 50 Hz frequency standard, various transmission voltage levels, and transmission line thermal and overall network power transfer and voltage stability limits. The main means of interaction between the controllers and all the grid equipment are computerised displays or Human Machine Interfaces (HMIs), and behind them the Windows based computerised monitoring and controlling system known as TEMSE. Through these means the controllers monitor and control all the equipment in the transmission network or grid.

A single shift consists of between 5 or 6 controllers who work for twelve hours at a time. During day office hours there are other staff members who work inside the control room making it a total of about 10 people present during the day. However after 5 PM only the shift members are present inside the control room. The staff on each shift work behind four “desks”. They are, the Loading desk, the Transmission desk, the Voltage desk, and the Power System Manager’s desk. Normally there are two computer screens per controller, on each desk, depicting the relevant information on the transmission grid together with a keyboard and a mouse used for control operations.

## 1.3 The New Working Conditions

The computer displays at the Eskom National Control Centre (NCC) have until 2007/2008, been using the ENCOR system of computerised grid monitoring and control.

However in 2007/2008 this HMI has been replaced with the Windows based alternative referred to as the TEMSE system. This changeover has received a variety of responses from the controllers (Muller 2010). Some have been in favour and some have had criticisms against the new TEMSE displays (as shown in the body of findings).

This event has been part of a process of adaptation, frustration perhaps in the beginning, but the process has unfolded without major incidents. In the NCC environment however, this changeover has some unique characteristics and presents unique challenges because of one critical factor. This factor is time. For most of their day controllers perform their work with the usual hassles of such a changeover without much difficulty. However it is under contingency conditions that the new displays can play havoc with their minds. When things go wrong, time frames for control responses become very short (from seconds to a few minutes) (Muller, 2010). Under such conditions the controllers rely more and more on “intuitive” or Naturalistic Decision Making (NDM) abilities. **In other words, when there is not enough time to think things through and use analytical engineering skills (as do the system engineers who perform network studies over weeks) the controllers’ subconscious strategies and tacit embedded training dominates (Klein 1999, Pinker 1999, Anderson 2002, Libet 2005).** This is what makes their work unique and extremely stressful, as the consequences of their rapid decisions can be devastating to the network, the public, and themselves. There has been an incident at the NCC where an individual committed suicide after repeated errors under contingency conditions due to the stress they experienced, which was compounded by personal problems (Muller 2010). In the recent past (last twenty years) only one or two controllers have actually retired out of the control room environment and survived longer than a year or two (Muller, 2010). These are quite serious realities and they set the tone within that working environment.

To make matters worse, since 2007, the Eskom network is under severe pressure as generation capacity is barely able to meet demand. Sometimes the network demand is equal to the total available generation instead of having a 10% margin as required by the NCC (Muller 2010). The reserve margin is meant to take care of demand fluctuations,

maintenance and other unscheduled outages, etc. This shrinking of the reserve margin has led to repeated blackouts in 2008, followed by scheduled rotated load shedding around the whole country, which lasted for three months, before other measures could bring the situation within tolerable, but not acceptable, limits (Muller, 2010). Such measures included agreements with heavy industry to reduce / manage load, domestic customer awareness campaigns, retrofitting of existing installations with efficient equipment (CFLs etc.), new emergency generation equipment like gas turbines, and other such measures. The bottom line is that the Eskom controllers' life has never been under greater pressure since 2008 (Muller, 2010). **It is therefore under such conditions that the changeover to the TEMSE displays needs to be seen to have the greatest impact on the wellbeing of the NCC staff, the functioning of the Eskom network, and indeed, South Africa and the region as a whole.**

## 1.4 The Investigation

With all this in mind this research was commissioned by Eskom in order to investigate what are the tacit or subconscious, visual, auditory, and kinaesthetic representations within individual controllers, which underpin their expertise (ability to control the network) and how they relate (are similar to or not) to the TEMSE displays. In other words the investigation aimed to find out if **the subconscious mental imagery, which spontaneously arises in the minds of controllers in response to the HMIs and is an integral part of their expertise, is different from what is presented in front of them on the HMIs or not, and whether this assists them or leads to confusion.** The research was designed to reveal what type of imagery and other tacit experiences arise spontaneously in the controllers' minds in response to the HMI displays. **Similarly with decision-making processes, the research was designed to reveal the tacit and explicit steps in the decision-making sequences, which were used by the controllers as well as the emotions and other contributing factors, which influence their work.**

The human controller being a critical link in the Power System chain, it would make a lot of sense to identify what the tacit representations in each individual are in order to:

- **Further refine their abilities** by bringing to the surface of conscious awareness their individual work related subconscious or tacit processes.
- **Identify the type of cognitive, simulator, and other training** required to improve the situation, as required for each individual controller, so that the mental adaptations required to use the new TEMSE computer-interface equipment can be facilitated.
- **See how newcomers' (in the control room) minds respond to the new equipment,** compared to those controllers who had mental images formed during the ENCOR era.
- **Identify tacit "best practice" protocols and practices** in order to improve the Naturalistic Decision Making abilities of all the controllers by creating suitable training protocols for Power System Controllers in general.

All the above as well as some other factors will be treated as areas for recommendations at the end of the thesis.

## 1.5 The Theoretical Background

In order to meet the objectives of this research a number of disciplines were consulted. They are: Power Engineering, Cognitive Psychology, Industrial / Organisational Psychology, and Neuro-Linguistic Programming. From the literature review it seems that this type of research has not been conducted anywhere else in the world in this type of environment.

The domain of this research is the tacit or subconscious realm behind observable behaviour of individual controllers, performing their work under particular circumstances. This domain is often alluded to when it comes to expertise, particularly when experts in high-pressure jobs, which require quick intuitive decisions, are involved (Klein, 1999). It is therefore very important to confidently assert, up front, that this dimension exists. Pinker (1999*, p 83).*), states,

> *"Discovering **the form of mental representations** (the symbol inscriptions used by the mind) **and the processes** (the "demons") that access them is the route of rigor in psychology, ... and **the information in an internal representation is all that we CAN know about the world."***

Other contributors to the field of psychology research make use of various terms alluding to tacit representations, such as concept formation (Bruner 2009), schemas (Bartlet 1932), mental maps (Senge 1994) (the information maintained in the mind of an organism by means of which it may plan activities, select routes over previously travelled territories, etc), and mental models (Bainbridge 1998), in an attempt to address the different layers of the levels of mental / brain processing from the unconscious, subconscious, and up to conscious awareness.

Similarly Senge, (1994), quotes from Howard Gardner,

> *"To my mind the major accomplishment of cognitive science has been the clear demonstration of …a level of mental representation, … **our "mental models" determine not only how we make sense of the world but also how we take action**."*

He also quotes Argyris (who has worked extensively with mental models and organizational learning),

> *"Although people do not always behave congruently with their espoused theories (what they say), they do **behave congruently with their theories-in-use (their mental models)**" (Senge 1994, p175). "**Mental models can be simple generalizations or complex theories but most importantly they are active, they shape how we act."***

He continues to say,

> *"the problem with mental models is not whether they are right or wrong…**the problem with mental models arises when they are tacit- when they exist below the level of awareness**." (Senge 1994, p 176).*

These views are not new, as early as 1930 Alfred Korzybski (Korzybski, 2000) stated that "**the map is not the territory**", referring to the fact that what we know of the world is never the world itself. **We can then postulate that since the creation of mental models (i.e. mental representations organized in various ways) is the way we relate to what we call the "world"; the differences in structure, content and operation of these mental models is what distinguishes experts from non-experts.** This observation is particularly true in cases where the expertise is cognitive and not a matter of physical prowess. However the big question is, how does one get to these mental representations, particularly those of experts. Neuro-Linguistic Programming pioneers, Bandler and Grinder, have demonstrated that it is possible to model the tacit aspects of cognitive and emotional expertise. They did this by means of Metamodel questioning techniques (Grinder & Bandler, 1975) and particularly the use of Sub-modality elicitation (Bandler & Macdonald 1988). The latter was the most important technique for eliciting the tacit visual, auditory, and kinaesthetic content of the controllers' experiences on the simulator, in this study. These techniques are theoretically underpinned by the work of Ramachandran (1997) who introduces the concept of qualia as the main distinguishing factor between actual tacit experience reports and general speculations. This approach has made it possible to investigate the structure and content of mental models, and it constitutes the main contribution of this research, which may then complement the work of other writers like Wilkins, Bainbridge, Johnson–Laird, Klein, and others. These writers have written extensively about mental models but have not reported on the content and internal structure of mental models of particular individuals, doing particular work. For instance, to say that a controller has a mental model of the network is not the same as to describe in detail what is the shape, colour, mental position, size and emotional impact (to name but a few characteristics) of the mental images in the controller's mind. Nor does it say much about how these tacit components relate to the images on the computer screens which the controllers use, and how the two interact to result in competent operations. The investigation of the content and structure of mental models in the minds of individual controllers within the NCC context is a primary contribution of this research.

Tacit expertise acquisition, because it is elusive unlike information transfer, which is quite explicit, remains an area that has not received much attention at present. This is because the word “expertise” is a nominalization for a large and complex set of mental structures/processes that have been constructed in the minds of “experts”. To the extent therefore that these mental structures or models are revealed “expertise” could be duplicated and “trained into” other people in the Eskom NCC. The expression “trained into” should not be construed to imply a cold mechanistic approach, as the quality of human relationship is paramount in the learning process.

From all the above elements and for the reasons listed, elicitation techniques were created/adapted for the NCC environment, by means of which the research was conducted. These techniques incorporate and expand on elements of Retrospective Verbal Protocol analysis (RVP) (Ericson & Simon, 1993), NLP Metamodel questioning and Sub-modality Elicitation techniques (Grinder & Bandler 1975; Bandler & MacDonald 1988), and general interview processes. By doing this the Tacit Retrospective Verbal Protocol (TRVP) analysis process was created.

## 1.6 The scope of the Research

It is the purpose of this research to reveal what are the tacit mental representations (visual, auditory, and kinaesthetic), which constitute the mental models held in the minds of the different categories of controllers (experts and novices) and if they match or differ from the TEMSE displays two years from its implementation. And how these and other factors either assist or impede the controllers’ expertise particularly when decision time frames are very short. These tacit representations will be presented in terms of content, and structure. The scope of the research is to probe beyond the level of data and consciously performed actions, to the level of the arising of tacit visual and auditory representations and processing, mental operational strategies, and internal decision-making sequences (which are normally lumped together under the heading “mental models”). In this way it is hoped that once the tacit representations have been identified, then, by means of comparisons, the findings of the research can be used to identify in

what way the computer displays play a role in enhancing or inhibiting the performance of each controller. From the findings, recommendations and strategies for training and other interventions will be put forth to be implemented as part of future work.

## 1.7 The Research Contribution

**The main contribution of the research will be to reveal the tacit domain of spontaneously arising imagery, auditory, and kinaesthetic experiences (underlying the general concept of mental models) in the NCC controllers' minds, in response to the new TEMSE displays. This is in order to facilitate improved work performance in the real world of Power System Control. A secondary contribution will be the expansion of the techniques currently used to elicit RVPs and the creation of the TRVP. This last step has been made possible because of the work of NLP pioneers Grinder and Bandler (1975), as well as Ramachandran (1997) who pointed out that the qualia-rich content of subconscious experience can be distinguished from the qualia poor rationalisations and explanations of controllers.**

**It is important to note that this is a new field of scientific investigation, conducted in a Power System control room setting, that such an investigation has never been conducted before, and that it is multidisciplinary in nature.**

## 1.8 Chapters

What follows is a list of the chapters in the thesis and their content.

**Chapter 2: BACKGROUND:**

In this chapter the following will be provided:

- **The** definition of the **problem** addressed by the thesis, the overall approach taken to solve it, and the **aim** of the research.

- The research hypothesis.

- The findings from the **literature review** and the discussion of the **assumptions, limitations, and contributions from existing knowledge, pertaining to this research, in the fields of** Power Engineering, Cognitive Psychology, Industrial / Organisational Psychology, and Neuro-Linguistic Programming.

- The fundamental requirements, which underlie controller behaviour within different time domains of operation of the national grid, and the type of HMI displays available.

- The **time domains** of operation in which the controllers have to work, and the importance of **the tacit domain** in situations where response times are short.
  The **visual appearance** differences of the old **ENCOR** and new **TEMSE** Windows based computer interfaces.

- The assumptions and limitations of the RVP elicitation model will be discussed.

- The creation of the Tacit Retrospective Verbal Protocol (TRVP) analysis.

- The research question.

**Chapter 3: METHODS USED.**

In this chapter the following will be provided:

1. **The overall methods and steps taken / used to conduct the research.**
2. **The participants' list with a table of pertinent characteristics.**
3. **The network simulator exercise details.**

4. **What was elicited during the interviews, the reasons for doing so and the methods used for each area of the research.**
5. **The methods of analysis used to interrogate the data for each stage of the research.**
6. **The equipment used.**
7. **Ethics**

**Chapter 4: RESULTS**

The results obtained by conducting the tests and interviews listed in Chapter 3 will be presented and analyzed as described in the methodology section under the following headings:

A. **Written feedback:** How the controllers described what happened during the simulator exercise in their own words without any input from the interviewer.
B. **Feelings / Emotions:** How the controllers felt during the exercise and how does that compare to what they feel inside the control room.
C. **Tacit Content:** The tacit mental representations, which arose while they were working on the simulator.
D. **Tacit Structures:** The tacit and explicit sequences and structures used by the controllers while working on the simulator.
E. **Adjustments:** Made by the controllers as they changed over from ENCOR to the TEMSE system of computer displays.
F. **Other Important factors:** Other important factors that foster or inhibit controller performance inside the control room.
G. **Value:** The controllers were asked if they found this whole process of value to them.

**CONSOLIDATED RESULTS**

A **consolidated summary of the findings** from the above results sections is presented at the end of this chapter in order to bring all the results together in a continuum.

**Chapter 5: DISCUSSION, RECOMMENDATIONS, AND CONCLUSION**

In the final chapter will be presented a **discussion** of the project as a whole with a description of the research contribution, the limitations of the research, and directions for future research, **recommendations** for improved controller performance, and a **conclusion where the contribution** of this research will be outlined.

Additional supporting material is provided in the appendices as follows:

**APPENDIX A:** The initial handwritten reports of what happened during the simulator exercise, as well as sketches depicting the controller mental images are shown.

**APPENDIX B:** The forms in which controllers reported how they feel in the control room, while working alone during a contingency, are shown.

**APPENDIX C:** TEMSE and ENCOR substation and voltage level screen images are shown.

**APPENDIX D:** Comprehensive results section

For convenience, each chapter begins with a summary of the main points covered and each chapter ends with a brief introduction to the following chapter. **Please note that the contribution of this research starts with Chapter 3. The material reviewed in Chapter 2 include extensive quotations, which serve to introduce engineering readers to this possibly "alien" field.**

In closing, consider the following scenario. A large commercial airliner is about to take off, loaded with a few hundreds of passengers, goods etc. If anything goes wrong and the plane crashes the event will be international headline news. The pilots responsible for such planes are high profile experts who receive great respect from all of us. On the other hand every day and for every 24 hours of each day a small group of controllers keep the

whole country, which includes millions of citizens and their personal and business interests, “flying” through all types of weather and other hazardous conditions while most of us remain unaware of it. These men and women are unknown and invisible to us, and worse, so are the invisible forces, which shape their expertise and by extension our lives on a national scale. This research is a first step toward shedding some light on these invisible forces and by extension improving the reliability of the whole Eskom network.

In the following chapter we shall consider what has been done before and how various techniques can be brought together in such a way as to accomplish our aim.

# Chapter 2:

# BACKGROUND

## 2.1 Chapter Sections

In this chapter the following will be presented:

- The definition of the problem addressed by the thesis and the overall approach taken to solve it.
- The aim of the research
- The research hypothesis.
- A brief introduction to the tacit and explicit domains as well as an overall rationale for this research.
- The findings from the literature review and the discussion of the assumptions, limitations, and contributions from existing knowledge, pertaining to this research, in the fields of Power Engineering (Network Visualization), Cognitive Psychology, Industrial/Organizational Psychology, and Neuro-Linguistic Programming.
- From the reviewed material above the time domains of operation in which the controllers have to work, and the importance of the tacit domain in situations where response times are short; the type of HMI displays available; the assumptions and limitations of the RVP elicitation model, will be discussed as they are the most pertinent.
- The creation of the Tacit Retrospective Verbal Protocol (TRVP) analysis, following the presentation of the NLP modelling methodologies.
- The research question.

## 2.2 The Problem Statement

There are a number of interrelated problems that will be addressed by this research:

- As things stand, two years after the implementation of the new computer displays at the Eskom NCC (TEMSE system) it is not known how the controllers' minds have adapted to the change (or not).
- The current Eskom network is in a critical stage where the load / generation balance is not optimal. This puts extra strain on the network controllers who have to work with very tight margins of error with the new TEMSE displays.
- At present RVPs (Retrospective Verbal Protocols) are used only to elicit activities, thoughts and other *conscious* events and experience of subjects, and not the tacit/subconscious representations in controllers' minds.
- The available elicitation techniques of tacit phenomena from fields like NLP have not been used to expand the range of RVPs in the field of Power System Control.
- Information about the tacit content in power system controllers' minds is entirely absent in the literature.

## 2.3 Aim

Since ancient times humans have attempted to understand the workings of the mind and later on the workings of the brain by "reverse engineering" techniques. More recent attempts, like the cognitive movement of the 1950s and 1960s (Pinker 1999), which explains the mechanics of emotions and thought in terms of information and computations and evolutionary biology which explains the complex adaptive design of living things in terms of selection among replications are combined under the term evolutionary psychology. This helps us to understand how a mind is possible and what kind of mind we have (Pinker 1999). Also, technological investigations of the working brain making use of fMRI (LaBerge 1990) and other techniques have presented a view of

the mind / brain phenomenon which is less open to speculation than before (Anderson 2002). In this sense the mind can be seen as a system of modules, which interact mostly below awareness. These tacit interactions result in cognition and emotional experience, as we know it. The general view is that the tacit processes underpin conscious experiences (Anderson 2002).

The aim of this work is to report on the results of implementing a program of appraisal of the subconscious processes underlying the experiences of the controllers working with the new Windows based displays (TEMSE system) at the Eskom NCC. It is the purpose of this research to identify how individual controllers' minds respond to the new Windows based interface two years after its implementation. In this study the mental (tacit, qualia-rich) and emotional responses of individual controllers as they work with the new system will be elicited by making use of the TRVP. Also, where it is applicable, these present experiences will be compared with those, which they had while working with the old system. A comparison between the old controllers' mental representations and those in the minds of the new controllers who have not been exposed to the old system will also be made. A number of other elements will be taken into account as discussed in the Methods chapter.

## 2.4 The Research Hypothesis

The research hypothesis is that, **"there are tacit mental structures, content, and emotions, which arise within the minds of the controllers at the NCC, as they work with the newly implemented Windows based TEMSE computer interface, and it these tacit structures and content which determine the controllers' response to HMI information when decision time frames are short."**

The purpose of this research is to investigate this hitherto invisible domain in a rigorous, repeatable, and systematic way, in order to expand our understanding of the hidden forces that shape behaviour inside Power System Control rooms.

## 2.5 General Considerations

The goal of this research was to identify exactly what happens at a tacit/subconscious level in the mind of a particular controller, doing a particular job, under particular circumstances, at the Eskom National Control Centre (NCC). This is quite different to what happens in the field of Engineering Psychology (Wickens 2000) where general theories of perception and human function are investigated. In order to justify the research hypothesis the following aspects were considered:

- First was **what controllers have to do,** with what HMI support and under what time constraints (Petroianu 2003, Muller 2010, Dy-Liacco 2002, Bainbridge 1968, Stag 1994, Frank 1982, Knothe 1989 Cristie and Mahadev 1994, Overbye 2002, Guttromson et al. 2007).
- Then, **what are some of the relevant, current, well accepted, theories regarding cognition at a sub-conscious level** (Pinker 1999, Anderson 2002, Libet 2005, Ramachandran 1997, Klein 1999).
- Then **the elicitation techniques available at present such as Verbal Protocol (VP) and Retrospective Verbal Protocol (RVP)**, which would be most appropriate to help us carry out the investigation, were selected, **and their limitations identified only as far as tacit content goes** (Ericson & Simon 1993, Thatcher 1995).
- Finally, **new components of elicitation techniques from the field of Neuro-Linguistic Programming (NLP)** (Bandler & Grinder 1975, Bandler & MacDonald 1988) were introduced to fill in the gaps and thus **a new elicitation technique, the Tacit Retrospective Verbal Protocol (TRVP) was created,** by means of which the research was carried out.

It is important to point out that this research is being carried out in an engineering environment/space and the intention is to **make a contribution to the field of Engineering Control Room Operations and not necessarily to psychology theory**. Various techniques and theory, as mentioned above, were combined in order to expand our understanding of what goes on in the minds of individual controllers. The extensive

**referencing and quotations of fundamental psychology theory** from standard textbooks is presented in order to facilitate the understanding of such information by mostly **engineering readers.** Such referencing would have been superfluous for a purely psychology based audience. The psychological theories presented and critiqued, are only discussed in order to establish current valid accepted theories of how brain/mind structures and processes work, and **not** to critically evaluate the psychological argument. This is because what is required is to establish a valid psychological foundation for the research. It is assumed that the literature presented below will be unfamiliar to engineering readers, and it is therefore "required reading" for such readers in order to appreciate all the elements which have gone into this research. It is for that reason that the lengthy literature survey was left in the main body of the thesis and not put into an appendix. If a reader wishes they can read sections 2.1, 2.2, 2.3, 2.4, 2.5 2.6, 2.7.1, 2.8.4, 2.9.1, 2.9.3, 2.9.4, 2.9.6, 2.10.2, 2.10.3, 2.10.4, 2.11.5, 2.11.6, 2.13, 2.14 only, as these are the most significant in the review, and then proceed to the next chapter.

## 2.6 The Tacit Domain and Qualia

**The term "tacit" also needs to be defined as it is used in this research.** Tacit is defined here as a term synonymous to the term subconscious. The subconscious mind is said to contain thoughts and feelings, which a controller is not directly aware of, but which can be brought to consciousness by means of specific elicitation questions. The subconscious exists just below the level of consciousness before the unconscious mind (Pinker 1999; Anderson 2002). Also the emotions, motivation, and operating decisions of the controllers are powerfully influenced by their past experiences, which are stored in the subconscious (McLeod 2009). On the other hand the explicit mind is the mind we are mostly aware of, the mind we describe and talk about when we say things like "I'm thinking about going to the sea this December" or in the case of network controllers "I am going to do such and such because I think this area needs reactive power support". In most, if not all studies on mental models, it is the explicit mind, which is observed by analyzing protocols, drawings, etc.

Becerra-Fernandez, and Sabherwal, (2010) make a different distinction about what is tacit and explicit knowledge. They state that knowledge discovery may be defined as the development of new tacit or explicit knowledge from data and information or from the synthesis of prior knowledge. The discovery of new explicit knowledge relies most directly on combination, whereas the discovery of new tacit knowledge relies most directly on socialization. In this respect they are referring to aspects of knowledge that are learned by association with others, such as attitudes and ways of doing things. As far as this research goes this is also important within the NCC environment, but does not refer to what is defined here as tacit. For the first category, data mining techniques are mentioned as an example. Such techniques can be used to reveal relationships among explicit data from which, by means of predictive or categorization models, new knowledge may be created. For tacit knowledge, the integration of multiple streams of experience is required for the creation of new knowledge. This occurs through the mechanism of socialization (Nonaka 1994, as cited in Becerra-Fernandez and Sabherwal, 2010). “Socialization is the synthesis of tacit knowledge across individuals, usually through joint activities rather than written or verbal instructions. By transferring ideas and images, apprenticeships help newcomers to see how others think” (Becerra-Fernandez & Sabherwal, 2010). Even though the acquisition of tacit knowledge is acknowledged under the term socialization the term is left ambiguous. The term socialization is not unpacked further to reveal what happens within the subject being “socialized”. In the present research some of the pieces of the “socialization” puzzle will be revealed in terms of their content and structure, particularly the term “how others think”.

For example, if we were to have a conversation about the Eskom network many things could be mentioned at a conscious level. However, here, what is required is to find out what are the specific images, sounds and emotions, which arise spontaneously in the mind of a particular controller when he or she is talking about a particular section of the network. What we are looking for are the actual images, if they are in color, their size, mental distance from the viewer, as well the amount of detail in such images. Similarly with sounds, like the internal “voices” which prompt a controller to perform actions, are

to be examined for tonality, orientation, intensity, etc. Finally the somatic experience or kinesthetic component of the controller's experience would form part of tacit information, in terms of their location in the body, texture, intensity, size, movement, etc. All the qualia elements (Ramachandran 1997) of the above modalities (visual, auditory and kinesthetic) are what will be investigated.

Qualia are the individual components of mental experience (i.e. the redness of red, the squareness of square, etc.). In the field of industrial psychology, when mental models are investigated, by means of protocol analysis, drawings, or performance protocols, etc., it is the researcher making inferences that is regarded as tacit information. This is a very important distinction. In order to make it clear that what the controllers reported on were actual retrospective descriptions of tacit/subconscious experience, it is the qualia aspect of their descriptions which is the main distinguishing factor (Ramachandran 1997). Ramachandran (1997) clearly states that qualia rich descriptions are the distinguishing criterion between rationalizations or speculation and actual, spontaneously arising, tacit experiences. This is a very important element of this type of research, which needs to be made clear up front.

The visualizations, which arise spontaneously in the minds of controllers and their components, are the most important elements of this research. **It is the elements of these images that are to be compared with the images on the HMIs in order to establish whether the controllers have mentally made the transition to the new displays at the tacit level.** This is an entirely new approach for the engineering field. Therefore, as these phenomena are investigated in the context of electrical network operation and control, where human controllers are the most important factor, it is important to be clear up front as to what we are setting out to do. Similarly if we were to speak of mental models, as they arise spontaneously, we are interested to find out what are the visual, auditory and kinesthetic components and the structure of these mental models, in the minds of individual controllers.

Finally as far as NLP goes, it is important to note that the field consists mainly of techniques and methods and not fundamental theory. This is the reason why in the relevant section of the literature review it is mostly such information (techniques and methods) that is presented. The "why" of these methods is mostly covered under the cognitive psychology section (Pinker 1999, Anderson 2002, Ramachandran 1997, Klein 1999).

## 2.7 Findings from the Literature Review and Discussion of the Assumptions and Limitations of Existing Knowledge

### 2.7.1 Aims of the Review

Here all the elements that contributed to the development of the research rationale and methods are listed and discussed.

The control of the Eskom transmission network involves many elements, namely:

- **The Primary Plant (PP).** The power lines, transformers, switch gear, etc., which comprise the transmission network.
- **The Secondary Plant (SP).** These are various interfaces and communication devices and circuits, which allow the network controllers to receive information about the state of the PP and to execute control actions.
- **The Computers.** Computers process the information received by the secondary plant and display it in various formats on monitors or Human Machine Interfaces (HMIs). They also act as input devices, which allow the controllers to send switching commands to various PP elements via the SP interfaces.
- **The Controllers.** These are the human experts who use the HMIs to maintain the network within specific limits of frequency (50Hz), conductor temperature (as per Eskom standards, usually with a maximum of $70^0$ or $90^0$ C), and

voltage level (1pu with a +-5% tolerance). These controllers play the most crucial role, as it is they who have the final say on all the other elements.

While it is known exactly how the first three elements behave we don't seem to know enough about what enables individual controllers to do their work. Here we are referring to the tacit enabling factors, which though invisible, underpin all activity of each particular individual controller in the short time frames in which they have to make decisions. Moray (in Gopher and Koriat 1999) shows a table of researchers who have worked on mental models of human controllers in various fields since 1969, as follows:

Table 2.7.1.A: Researchers who have contributed to the field of mental models research (Gopher and Koriat 1999).

| Some Applications of The Concept of Mental Model | |
|---|---|
| | |
| Bainbridge 1974 | Industrial process control operators |
| DeKeyser I986 | Industrial process control operators |
| Dutton and Starbuck 1971 | Scheduling in discrete manufacturing |
| Gentner and Stevens 1983 | Simple physical causal systems |
| Green 1990 | Human-computer interaction |
| Hoc 1995 | Aviation and process control |
| Jagacinki and Miller 1978 | Perceptual motor skills |
| Jex and Clement 1979 | Complex manual control |
| Johnson-Laird 1983 | Deductive reasoning |
| Rasmussen 1986 | Industrial Fault Diagnosis |
| Rouse and Morris 1986 | Knowledge representation |
| Sanderson 1990 | Electronic troubleshooting |
| Sheridan and Johannsen 1976 | Supervisory control |
| Stassen 1979, 1988 | Supervisory control and mental workload |
| Veldhuijzen and Stassen 1977 | Navigation of supertankers |
| Woods and Roth 1988 | Cognitive engineering |
| Young L. 1969 | Complex perceptual motor skills |

Authors like Bainbridge (1998), describe how mental models are constituted using various examples of depictions drawing from authors like Rasmussen (1974,1979,1981) and Johnson Laird (2001, p 434) who discuss how, "reasoners use the meanings of assertions together with general knowledge to construct mental models of the possibilities

compatible with the premises". Collectively, their contribution to our understanding of how human controllers perform their work is immense. However their findings seem to be generalized theories of mental models, describing and explaining all the possible processes that may be going on while the users of mental models work in their respective environments. In all their writings no actual descriptions of the content of such mental models, or the qualia (Ramachandran 1997), which constitute them is presented. In this research what will be investigated is what is actually going on in the mind of *individual* controllers. What shape, size, and color, are their mental images? What do the voices they hear in their mind sound like? This is in order to better understand what happens when, for instance, the controller responsible for an operating error is unable to say what actually happened. Or when a controller says that they saw something different than what was on the computer screen in front of them after an error, what did they actually see? Also, when an experienced controller is asked to describe what makes them good at their work and they shrug their shoulders and say things like, "It takes time to gain experience", what are they referring to, what happens over time? This inability to describe the tacit aspects of experience, as defined above, represented a seemingly impenetrable barrier to gaining information about what makes the controllers competent. This is similar to seeing the display on a computer screen and not being able to access the programming code, which is responsible for it. In the context of this discussion when we speak of controllers we are really referring to the responses of, or in, their brains (depending on what state they are in) to the HMI displays. This imbalance between knowing so much about the first three elements of the transmission network and not so much about what goes on within the minds of individual controllers, in the Power Grid Control field, can have many undesirable consequences as identified from the discussions, which took place with all the NCC stakeholders (Muller 2010). It is with all this in mind, that the literature in the following four fields was consulted and the findings from each field integrated to support the research.

**The general sequence of review was as follows:**

- First it was required to find out what is the state of the art in the field of visualization of power systems.

- Second came the identification of what are some of the main current theories of cognition, particularly the information pertaining to the tacit aspect of mental models.
- Third came the identification of the available elicitation techniques of mental experiences, from the field of Industrial Psychology, particularly the elicitation of Retrospective Verbal Protocols (RVPs).
- Finally, other elicitation alternatives were identified from the field of Neuro-Lingustic Programming (NLP) in order to create the Tacit Retrospective Verbal Protocol (TRVP).

Here are the four areas of investigation in brief:

**A. The Field Dealing with Power System Control, and HMI Display Design.**

From this area of knowledge the performance requirements placed on the controllers became clear. This is particularly important, because when the time frames for response to contingencies, and network stability requirements, become short (a few minutes or less), tacit processes seem to dominate (Libet 2005, Anderson 2002, Klein 1999). It was therefore necessary to know the following:

- The actions that controllers may be asked to perform (Petroianu, 2003)
- The time frames in which the controllers have to perform their work, in order to maintain the network within its operating limits (Mitsche 1993, Muller 2010).
- What the displays in front of them could be showing (their format, information displayed, etc.) (Muller 2010, Christie, Mahadev and Overbye 2008)

Power System Visualization is an area of research and development where the design of computer interfaces is optimized in order to enable humans to reduce the time it takes them to convert data into information (Bainbridge 1968). However the reverse is not done

i.e. the tacit requirements of humans do not seem to be the starting point for HMI development. A number of published papers and reports were reviewed. From these, it became apparent that in this field the term visualization is used to describe efforts at improving computer display styles and data management techniques but not their optimization with respect to the tacit processes within the operators directly. In this field visualizations refer specifically to the way that HMIs give visual representations of the system state to the controllers and NOT the internal visualizations that controllers have of the system. Optimal design, using information from an area of study called "joint cognitive systems" (Brezillon & Pomerol, 1997) is intended for the two to match one another. This is what will be discussed at the end in the recommendations.

The designers of such interfaces do not seem to be properly informed of the tacit structures in the controllers' minds and therefore they produce designs according to general hypotheses about best practice. The displays are then tested for suitability mainly on university students (Overbye 2000, 2002, 2008). **Real experts** in the field are seldom consulted, and even when they are, they **seem unable to describe** the tacit domain as is often shown by their recommendations (Frank, 1982). In terms of Situational Awareness (Wickens 2008), the awareness of controllers needs to be expanded to include the awareness of their internal environment (Lazanas 2007, 2010) in order for them to be able to report about tacit phenomena.

## B. The Field of Mental Processing and the Tacit Domain from Cognitive Psychology.

The latest theories about human performance postulate many unconscious and subconscious domains (Pinker 1999, Anderson 2002, Libet 2005, Ramachandran 1997, Klein 1999). The theories cited posit, among other things, that unconscious and sub-conscious processing of information are at the heart of complex decision-making and visualization, particularly when this takes place in short time frames. Also the concept of qualia (Ramachandran 1997) as the building blocks of inner experience and the main

distinguishing factor between tacit experience and rationalization is discussed. This last item is what validated the elicitation process.

## C. The Field of Industrial Psychology and Cognitive Ergonomics for the Elicitation of Retrospective Verbal Protocols in Particular.

This field was consulted in order to identify suitable elicitation techniques. One well accepted technique for the elicitation of information from experts is that of Verbal Protocol (VP) analysis (Ericson and Simon 1993). Traditionally Verbal Protocols have been about the verbal description of consciously accessible phenomena as they occur. An extension of VPs is the use of Retrospective VPs (RVPs) during which the person interviewed reflects on past experiences and reports on them. However in the literature reviewed the tacit elements of such experiences are not reported on (Ericson & Simon 1993). This constitutes an identified shortcoming, which this research will address by means of the introduction of the Tacit Retrospective Verbal Protocol (TRVP).

## D. The Field of Neuro-Linguistic Programming (NLP) for Elicitation Techniques Pertaining to the Tacit Domain.

The foundation of NLP is the modeling of the invisible forces, which shape excellence in human performance. It is the modeling of the tacit aspects of performance that have made NLP elicitation techniques an excellent tool for such work. The Metamodel process of eliciting the underlying meaning of verbal descriptions (Grinder and Bandler, 1975), and sub-modality elicitation (Bandler and Macdonald, 1988) form the foundation of the interview process used in this research, as underpinned by the qualia theory as presented by Ramachandran (1997). These two techniques were used to form an extension of the traditional RVP and thus the Tacit Retrospective Verbal Protocol (TRVP) process was created.

What follows are the detailed findings from the literature review conducted in these four areas. At the end, the relevant elements from each field are presented in a synthesis, in a way that shows how they all fit together to address the shortcomings of existing methods, and the contribution of this body of research.

## 2.8 Review of the Field of Power System Visualization

The first area to be reviewed was power engineering, under the heading of Power System Visualization. Information in the form of research papers and commissioned reports was retrieved from the early 60s to the present. What follows, is a summary in approximate chronological order of the main ideas presented in the above papers and reports.

### 2.8.1 Power System Elements

Firstly, we have a list of the Power System Elements, Operations and Techniques as they relate to what controllers have to deal with in their daily work (Petroianou 2003).
They are presented as categories with sub-fields below.

**Power System Components**
Power Generation
Electrical Transmission Networks
Substations & Equipment
Protection & System Automation
Power Demand (Loads)
Enabling Technologies (SCADA / EDS)

**Operation**
Normal Conditions
Emergency Conditions

**Control**

Frequency - Active Power Control

Voltage - Reactive Power Control

**Optimization**

Power Economics

**Quality Of Supply**

Power Quality

**Regulatory & Institutional Environment**

Operation under Competitive Conditions

It is within this set of parameters of the power system, that the Eskom network controllers of the high voltage national grid have to operate. This is also true of network controllers around the world. The general approach taken by utilities is that they hand over equipment and operating regulations to the controllers, to which the controllers must adapt, in order to operate their respective networks.

### 2.8.2 Power System Phenomena

Mitsche (1993) lists the power system phenomena that controllers have to deal with.
He introduces the time frames that pertain to each one of them, the power system controls that apply, as well as some of the simulation tools that can be used to address them, as follows:

Table 2.8.2.A: Power System Phenomena, available Power System Controls, and appropriate Simulation Tools (Mitsche 1993).

| Power System Phenomena | Power System Controls | Simulation Tools |
|---|---|---|
| **Surges** ($10^{-4}$ to 0.1 s) | HVDC, SVCs, Generation Control | Surge Software |
| **Power Swings** (0.01 to 10 s) | Prime Mover & Generation Control Low Frequency Control (LFC) | Dynamic Simulations |
| Frequency Variations(10 s to 1 hr) | Prime Mover Control, LFC, Controller Actions | Power Flow & Optimimal Power Flow |
| **Economics** (5 min to 1 day) | Pr. Mover Control, LFC Controller Actions | Security Constrained Optimization & Unit Commitment |
| **Operations Planning** (1 hr to over 1 year) | Prime Mover Control, LFC, Controller Actions, & System Reinforcement | & Production Simulation |
| **Planning** (months to years) | System Reinforcement | Reliability |

Notably the domain of Voltage Stability control is left out in the above list, yet this is the most dynamic and important area of intervention within the South African NCC. This is an important omission, which is particularly important for this study as the tasks given to the participants were designed for voltage stabilisation. Transmission network voltage fluctuations and network voltage stability control are a major factor in the day-to-day work at transmission control centres. Voltage control is the most dynamic and demanding area of work at the Eskom NCC (Muller 2010). The required response time frames associated with voltage control functions are very short. Typically they range from seconds (under contingencies) to five minutes (under normal conditions) (Muller 2010). This means that if the controller responsible does not attend to the situation or contingency at hand within such time frames the system voltage will collapse with severe consequences to the whole system operation. This has been particularly so since 2007 where the balance between generation and load has reached critical levels in South Africa

where sometimes there is more demand than generation. The required norm is that there should be at least a 10% generation surplus (Muller 2010).

It is pointed out in Mitsche's paper (1993) that the trend is for more powerful computers doing more and more data processing. The results of such processing however, are presented to less experienced engineers that have neither the time nor the background for traditional case preparation or analysis. Mitsche (1993) makes a strong case for filling in the data where information “gaps” exist. This means that data preparation, case selection, and most importantly results analysis, must be carried out by the invention and development of progressively more sophisticated HMIs. Within the short time frames that voltage control takes place however, another dimension of analysis will have to be added, as there is no time for conventional information processing by controllers, which takes too long.

### 2.8.3 Development of Energy Management Centres

Dy-Liacco (2002) states that in 1972 there were about 10 Energy Management Centres in the world. This number has grown to over 600 at present. Not only have their numbers increased but so has their level of complexity, as the variety of functions that they perform have multiplied. These centres originally served a limited, exclusively technical function. Now they have evolved into highly computerised hubs, with links to market operation centres or power exchanges, transmission control centre hierarchies, intranets, extranets, virtual private networks, links to other such centres and business networks. This has been the result of pressure exerted on the power industry by governments, large industries, and investors to privatise, restructure, and deregulate. The paper concludes by emphasising that not only are control centres here to stay, but every effort should be made to ensure their integrity and functionality under accidental or intentional catastrophic event conditions.

In the context of this work however, even though every effort is being made to optimize the control centres not much is being done to make explicit the hidden forces, which

underpin human performance within those centres. In this respect, Bainbridge (1968) in an article aptly titled “Study of Real-time Human Decision-making using a Plant Simulator” identifies a lack of knowledge concerning the thought processes of controllers. Further, it is stated that it is still common to find well-designed control rooms, which supply men with information that they do NOT use. This is true even today (see Muller, 2010). As Bainbridge (1968 p91-106) very aptly puts it,

> *“…controllers do not want information on the control panel they want it in their heads”*.

Even though researchers like Bainbridge (1968) point out that information is processed in controllers’ minds the tacit *content* of the processes involved remains undefined and thus invisible. It’s not sufficient therefore to say that controllers use mental models or schemata and not provide information about what these actually are in terms of content and structure. This may sound obvious, but it appears that internal processing strategies and visualizations of expert network controllers are entirely absent in the literature reviewed in this field. It is present however in NLP elicitation of expertise models literature (Bandler & Grinder, 1975). Also by not knowing how information is absorbed and processed by network controllers, any strategy that is employed to improve their working environment is a hit and miss attempt at best.

The first Power Industry Computer Applications (PICA) conference, held in Phoenix Arizona in 1963, outlined the efforts made to address the issues of Power System management and control with computer assistance. The follow up conference, held thirty years later in 1993 (Stag et al 1994), provided the perspective on the way that computers have been used. They have been used to facilitate efforts that make the national grids around the world easier to operate, as well as to reduce the tragic consequences when these efforts fail. In 1964 IBM introduced the 360 family of computers. The great Northeast blackout of 1965, in the USA, made it clear that operator control with computer assistance would be a must. The results of that are the energy management systems that we have today (Stagg, Abibi, et al. 1994).

In those days there was great opposition to digital load flow programs as analogue methods “seemed” more natural. This goes to show that views do change over time, as this is no longer the mainstream view and digital load flow programs predominate at present. In the 1960s two schools of thought emerged. The proponents of the first, put forth the idea that the network should be designed in such a way that whatever happens to it should have been foreseen and planned from the start. The members of the second school believed that with proper operation and control, one could address the power system problems as they occur.

Another major power disturbance in the US during 1967, indicated that the dynamic models of the day were inadequate and that there was a need for on-line monitoring and control. Power Systems needed sensors, communication, computers, displays, and real time controls. In 1967 IBM developed a network control Energy Management System (EMS) worth $15 mil (over $60 mil today), which was rejected on financial grounds. It could cater for 1 Main Operating Centre, 3 Regional Centres, 14 Generators, and 28 Bulk Distribution Stations with a total capacity of 2230 MW. Today, over $2.6 bil. of EMS equipment is installed. It is stated in the paper that in 1993 we were somewhere above the lower bend of the EMS development “S” curve (Stag, Abibi, et al. 1994).

Similarly in Europe, Power System Computation Conferences (PSCC) have been held since 1962. Eventually collaboration with the USA followed and this has continued up to today. This has led to the emergence of new analysis techniques such as Expert Systems, Fuzzy Systems, Neural Networks, Simulated Annealing and Genetic Algorithms, to name some of the most current techniques (Stagg, Abibi, et al. 1994). It is important to note, that in 1975 there were almost 8000 registered Power Engineers in the UK and in 1990 only 5000. This trend would make them extinct by 2002 (Stagg, Abibi, et al. 1994). Although not extinct at present, power engineers are in short supply. This further supports the case for effective computer assisted network control, as it appears that the interest in Power Engineering studies is not on the increase and older experienced engineers are retiring (Muller 2010).

Returning to computer technology, early algorithms using 100 words of memory were considered “appalling” and all that was analysed was transient and steady state stability. By 1993 we had short, medium, and long-term stability, angular stability, voltage stability and we use Eigen value methods for small disturbance stability. These are not just new tools, but new ways developed for viewing the network and its operation. Further, expert systems and artificial intelligence will play a key role in future developments (Stag, Abibi, et al. 1994). Optimisation, with its plethora of meanings, has been added to the requirements placed on the network planner and controller. These require even broader, more complex and comprehensive models for viewing the network, which often lead to information overload. In this way the tacit requirements on the controllers is being expanded as the idea of optimization implies that they will have to take into account the performance of their networks over time and not just in the present moment.

The creation of hierarchical clustering within power networks is one emerging trend to facilitate the visualisation of the complexity of the networks. In a report on “Human Factors Review of Electric Power Dispatch Control Centres” commissioned by the Electric Power Research Institute (EPRI) (Frank 1982), the information requirements of the controller, for normal as well as emergency network operation, were identified and evaluated (this information is old but most of the elements presented are still relevant). The report found that the amount of information a system controller needs is so large, that further classification was required. This classification went from Pre-dispatch, Dispatch and Post-dispatch, to system states of Normal, Degraded and Restorative. Here we have a good attempt to identify the different modes of control required.

### 2.8.4 Response Times and Requirements of Energy Management HMIs

In addition to these modes, the study (Frank 1982) examined the impact of response time to system-controller information requests, the impact of the control-system condition on controller information needs and the impact of system operation information on controller training. It was also made clear, that the report is but a summary of

information. Individual utilities remain distinct and at no time are the findings to be presumed to be definitive for all controllers. Again no detail means that the implementation of the report findings becomes difficult, as how does one determine what is suitable in a particular context? The above-mentioned information was gathered by means of Interviews with Utility Management and Staff, Interviews with the Controllers themselves and a controller Information Needs Survey. This information gathering resulted in a collection of operating procedures, logs, hard copies of selected CRT displays, etc. The point made, was that large sets of raw data have to be transformed into useful information for the controller. In the third phase of the study, improved methods for managing and presenting data to the controller were identified (Frank 1982).

In this respect, the following were considered:

- Information “chunking” and the time intervals between chunks.
- Entry verification time.
- Response time during controller-system interaction.
- Response time to controller inputs.
- Response time to controller requests.
- Response time variability and its relation to system states (normal or not).
- Scan rates as well as controller response times.

Further, it was shown that controller response speed increased with raised stress levels, up to a point where it abruptly reached unacceptable levels. This is a fundamental limitation of the whole process of power system control, as the controller is the one on whom all the other systems converge in order for the network to function properly. Frank (1982) also raised the issue of stress as an important factor that should not be underestimated. Again the tacit domain and the internal stress factors, which either activate or inhibit performance, are acknowledged without explicitly stating what these factors are.

The significant parameters of time lines of the control system are (Frank 1982):

- The time for the control system to respond to controller action / requests.
- Consistency of time related aspects of control system operations.
- Control system conditions.
- Prominent effects due to response times of the control system on the operator are:
- Subsequent performance of the human operator.
- Disruption of the operator's thought processes due to time delays.

The following response times were highlighted as upper limit response times for HMIs (Frank 1982):

- 0.2 sec for the computer to respond to controller keyboard entries.
- 2 sec for operations between the controller and the system.
- Longer than 2 to 5 sec response times were found to be disruptive for interactive situations but were suitable for computer processing of a request by a controller (and sometimes longer than 5 sec.).
- 5 to 15 sec responses (provided that within 2 sec a message is received to confirm receipt of request) are suitable for complex problem execution requested by a controller.
- Greater than 15 sec intervals are only suitable for performance of extremely complex routines.

This is another way of saying that tacit processing and responses take time as implied by the standards set above. These times further depend on the system's state of emergency and the controller's stress level. The idea is not to disrupt the controllers' (automatic or tacit) thought processes. It must also be borne in mind that humans are highly adaptive and therefore deviations from the above are tolerable so long as alternatives are sought that will minimize the disruptive effect. These sorts of time frames do not allow much time for purely conscious processes and as a result the importance of tacit expertise, which comes into effect automatically, is starting to become clear. Also the fact that we

are referring to optimum times implies that there is something going on in the minds of controllers which has its own timing.

A number of desirable controller aptitudes and training objectives were listed, with particular emphasis on stress (management and reduction) and the use of simulators in general. In conclusion, the report states that at that time, controllers were not being presented with all the information that they needed. Instead, a large volume of raw data was provided which was not converted into useful information on time. A list of **13 proposed recommendations** follows; these would go a long way towards addressing all the above-mentioned shortcomings (Frank 1982). They were:

- Develop and present more transformed data (data to information).
- Present this information in varying time domains as per system state and operating conditions.
- It is to be accepted that controllers require information in a way that will aid them in restoring the system to its normal state.
- The overabundance of raw data during degraded power system states should be reduced.
- The controller should be informed of significant changes and their consequences at a higher level of priority.
- Dynamic methods of detection, utilisation and display of power system abnormal operating states should be implemented in application software and in warning systems.
- Overall integrity of system communications should be displayed to increase confidence in decision-making.
- The priority of system state information provided should be based on the levels of power system states.
- Post-dispatch functions (logs, reports, etc.) should be automated.
- Alarms should be dynamically prioritised and only displayed at stations where they are of value.
- Information about individual events should be combined into:

- Power system element alarms.
- Islanding and power balance.
- Power system elements most endangered.
- Prioritised appropriate action.
- Time remaining to take action (time-to-go).
- Predictive algorithms should be utilised for State Estimation, Power Flow, Contingency Analysis, and Preventive Actions.
- Load shedding and similar operations should be automated based on system performance.

The above list of factors remains relevant today, as it was when it was produced.

In this report (Frank 1982) it is acknowledged that controllers' mental processes must not be disrupted by what is displayed by the computers. This is in order to assist them to process and respond to information. However no mention is made about what goes on in the controllers' minds so as to know if it is being disrupted or not. Controller aptitudes and training objectives were mentioned as areas of consideration but these recommendations were limited to the explicit domain (i.e. what controllers should do rather than what they should be aware of internally).

### 2.8.5 Stress

Authors like Hockey have gone further into the human domain by recognising the role of stress within control room environments (Hockey et al. 1989). Hockey et al. (1989) discuss the impact of the ensuing stress on controllers who experience heavy cognitive loads arising from the difficulties associated with trying to control a system via computer interfaces and other activities like planning, decision making, as well as the interface itself. Even though Hockey et al. acknowledge the cognitive demands made on controllers as well as the resulting stress that arises from their work they do not provide any information about tacit phenomena.

Knothe (1989) goes further still, he states,

> *"Insight into the nature and behavioral characteristics of the human being have to be sought from the field of industrial psychology"*.

This is because human beings are directly and critically involved in the control loop. He continues with acknowledging the importance of accommodating the ergonomic needs of controllers but falls short when it comes to the tacit domain. He concludes that from the design point of view, the controllers themselves must be involved from the start. However, that is not enough, as there are varying opinions about what is desirable and people get used to what they have, perceiving changes in a suspicious way. This is what happened at the Eskom NCC where mixed opinions were presented according to each person's preferences (Muller 2010) regarding the new TEMSE displays. Knothe (1989) recommends that more input be obtained from the human engineering sciences.

### 2.8.6 HMI Design

As far as Human Machine Interfaces (HMIs) themselves go Mahadev and Christie (1992; 1994) present an overview, of the state-of-the-art at the time, of HMIs and Power Network Visualisation. They state that existing representational methods, at the time, mostly presented large sets of numerical data, which then had to be interpreted by the network controllers. This is a very inefficient approach, as it does not take advantage of the natural cognitive abilities of humans (such as pattern recognition, colour association etc.). By acknowledging the pattern recognition requirements of controllers the authors come even closer to the tacit domain. In broad terms they state that there are specific steps that controllers go through in order to interpret the network within their minds. To the extent that the technology that is used to represent the state of the network can present information suitable to their cognitive requirements (images rather than numbers), then the controller's work becomes easier and faster.

In the table below they show (Mahadev & Christie 1992, 1994) the steps that a controller has to go through to extract high level information about the state of the network from purely numerical output data from an “old style” **Power System Analysis Tool (PSAT).**

Table 2.8.6.A: Steps taken by a controller in order to extract high level information about a network (Mahadev & Christie 1992, p1085).

| PSAT operations | Controller mental processing |
|---|---|
| Collection of data | Recognise data items |
| Computation | Build mental model |
| Presentation (numerical) | Interpret the model (analysis) |
| | High-level information extraction |

Here it seems that they imply that the controllers perform all their work consciously, as in something is recognised, a mental model is built and some sort of interpretation follows consciously. This type of thinking does not give proper acknowledgement to the tacit domain, where for instance a controller will enter the control room, scan computer screens from a distance, get a "strong feeling", and then go look closely at the screens to see what is going on (Muller 2010). Nor does this approach account for the fact that a controller may not be able to distinguish between what is on the screen compared to what is in their mind (e.g. the Perky effect, Nigel 2010). The Perky effect stipulates that a controller may confuse what he sees in their mind with what is presented on the HMIs under certain conditions, like when fatigue is present. The authors continue by identifying the shortcomings of the available visualisation tools of the time, given that these tools are used for **Control** (results are automatically applied to system operation); **Operation** (human operators make use of results and act based on their interpretation); and **Design** (engineers interpret results to make design decisions). These tools produce results that consist mostly of numbers instead of the high level abstractions that humans use for mental problem solving. From the above they conclude, “The purpose of computing is

insight not numbers" (Mahadev, Christie 1992, p1084). However they do not distinguish between the different needs of engineering staff who perform control functions in very short time frames relying of tacit processes, from those who do planning over long periods of time where cognitive processes and analytical skills usually dominate. Further the concept of insight is a vague term, which directly points to the tacit domain but at the same time leaves it unattended. The Metamodel questioning technique (Grinder and Bandler, 1975), which will be discussed later on, will be used in order to get past such vagueness during the course of this research.

One main reason that human controllers have difficulty in using large numerical data representations is that conscious processing has upper limits, as shown by Miller (1956), who demonstrated that a maximum of 7 +/- 2 chunks of information are all that a person can process consciously thus making large numerical data sets difficult to use. This is true for novices in the NCC, but the experts have a different experience as they "at a glance", "intuitively", assess the state of the network even from purely numerical displays (Muller 2010), indicating that the way that they "chunk" information is different. In short the authors conclude:

- Large sets of data are difficult to display all at once.
- Computer screens have limited capacity to display results.
- More powerful computers produce larger volumes of data.
- The use of alarms is useful when only a few of them are activated, during critical disturbances; however, the number of alarms generated is too large.

When the output of a PSAT is presented in a graphical format however, the controller's work is made easier as shown by the table below (Mahadev & Christie 1992).

Table 2.8.6.B: Steps taken by a controller when information is presented in a graphical format (Mahadev & Christie 1992, p1086).

| **PSAT Operations** | **Controller's Mental Processing** |
|---|---|
| Collection of data | Analysis |
| Computation | High-level information extraction |
| Presentation (graphical) | |

However, not all graphical representation methods are suitable for power system operation. In general the authors (Mahadev & Christie 1992) list the following existing unsuitable practices:

- **Data maps** (geographical map), the current (1992) practice is to use such geographical representations of the power system. However, they are single line diagrams with lots of numbers on them that have the above-mentioned disadvantages.
- **Time series** (data vs. time), this type of representation (like swing curves of generator angle versus time) used for stability studies, power demand curves for different times of the year, etc., are useful when there are only a few variables.
- **Relational graphics** (plots of one variable against another) are limited to three variables, since we only view in three dimensions thus also limiting the number of variables displayed.
- **Kiviat diagrams** (summary based) rely on the symmetrical representation of a few variables of comparable significance. They become ineffectual in power systems representations of line loading or voltage profiles, as they require further interpretation to sort out the significance of a disturbance, its location, the degree of the disturbance relative to the overall network state and its relationship to other parts of the network.

On the other hand there are three keys to designing effective graphical representations, they are:

- Natural encoding of information (using images common to users).
- Task specific graphics (clean images of predetermined meaning).
- No gratuitous graphics (unnecessary clutter).

From the above information it would seem that the ideal representation would be a physical realisation of the mental image of the network that controllers create within their minds, after scrutinising and integrating a multitude of data. However nothing is said about how to obtain such images, tacit or otherwise, or if these images change (become simplified, Lazanas 2010) in the minds of controllers as contingencies escalate.

The case is also made that a geographical representation of the network is preferred, since it makes use of the natural ability of humans to remember and reason about geographical data. The authors conclude by stating that the above methodology would be presented to network controllers so that they can offer comments as to its suitability in meeting their needs. Again, in stating that, the authors hope that tacit domain information may be revealed indirectly as controllers give feedback (Mahadev & Christie 1992; 1994). Even though the term “natural cognitive abilities” is mentioned it is not demonstrated what this actually means. Further it is stated that automatic control systems, human controllers, and design engineers have different data and / or information needs, thus acknowledging the tacit needs of each group. From the above they conclude that for controllers in particular “the purpose of computing is insight not numbers” (Mahadev & Christie, 1992 p1084) However, the internal representations of “insight” are not identified. Even though they emphasize that human controllers have difficulty in using large numerical data representations it has been shown that experienced controllers can scan large numerical data sets of computer screens and get a “feel” of impending contingencies (Muller, 2010).

Mitsui and Christie (1997) further developed some of the above concepts where they indicated voltage violations by means of boxes that extend above a norm value for over voltage violations. For under voltage violations the voltage boxes extend below the norm

levels. The colours used must be carefully chosen so that they meet the needs and expectations of end users. In this respect what is particularly interesting about the paper is the concept of **"Kansei"**. This word means human intelligence based on sense or instinct rather than logic. In this respect the psychological meaning of colours as well as colour sense and sensitivity taking into account colour intensity and saturation were used to select the display colours. The choices were then tested with network controllers to validate their worth in a control environment. It seems that the introduction of hue as opposed to simple saturated colours involves the human operator and his sense of discernment (or Kansei) thus creating a richer control environment allowing for greater complexity depiction. The results of the evaluation of this approach by controllers were preferred for evaluating voltage profiles and identifying violations and voltage differences particularly when they are large. It can be said therefore that this approach represents a further step on the road to the realisation of the tacit influences which shape controller performance in power system control centres particularly as the sub-categorizations of colour are very similar to sub-modality criteria.

Mahadev and Christie (1996) pointed out that any effort exerted by controllers that does not change the power system is "overhead". This is another way of saying that the match between what controllers have in their minds and what is out there on the screens is all that matters. As a result a good User Interface (UI) should reduce such effort to a minimum. The Task Adaptive Visualization (TAV) approach is centred on the concept of "Show me what I need to see" and therefore some form of decision-making by the designers of the computer tool is assumed. Further in the paper, it is stated that the Full Graphics User Interface (FGUI) has not improved matters in the control room, as it requires effort to manipulate the interface. This is not an improvement in overall efficiency compared to the traditional Character Graphics User Interface (CGUI). Again from the tacit point of view this means that any information presented on the screens which interferes with what is going on in the minds of controllers is to be avoided. Instead the UI should be task-oriented providing the information needed to perform a task at one place. It should also consider the relevant information that needs to be displayed

and the means to display it. In all these statements the authors keep referring to the tacit domain but do not directly acknowledge this.

Mahadev and Christie, (1997) discuss the development of graphical representations for a global display of power system security states for sets of contingencies. The main premise is that it is no longer a problem to compute solutions to network contingency sets but rather to display the formidable amounts of numerical data that result from such computations. In conclusion the authors state that whatever methods are developed they need to be evaluated by the relevant network controllers to ensure their relevance to their task of practically running the network. This is another way of saying that ultimately what goes on in the controllers mind *will* determine the usefulness of any control interface.

Overbye and Weber, (2000) and Overbye, (2000) provide similar findings. The visualisation methods introduced in Overbye and Weber (2000) are:

- Animation of Power System Flow Values.
- Contouring of Bus and Transmission Line Flow Values.
- Data Aggregation Techniques.
- 3D Visualization

Of the methods outlined in Overbye and Weber (2000), 3D interactive visualization is the most comprehensive and the most sophisticated, as it incorporates elements of the previous methods. The paper concludes by pointing out that work needs to be done to address broader challenges. These would include the problem of visualising the potentially large number of contingency states of a network as well as the impact of a large number of power transfer operations at once. In this respect the authors seem to imply that the tacit domain may have more than two dimensions and as result presenting information in this format it may be possible to awaken this faculty, which had been dormant as HMIs represented information in a 2D format.

In Overbye's (2002) report like those before it, the need to present vast amounts of data in a way that it can be assessed in an intuitive and quick manner is stressed, but he does not say by whom as the needs of novices and experts are different (Muller 2010). In this case the relationship between actual network power flows, scheduled power flows and the capacity of the transmission system to accommodate them safely, is considered in light of the fact that there is a move to create single entities (independent system operators or pools) that will control much larger transmission systems than at present. Overall, the controllers in the report recognised the new displays as a significant enhancement to their previous system views. The report, however, emphasises that in order for the new displays to be accepted, it is imperative to keep the end users in the design loop from the beginning, so that they can recognise and express their needs clearly. Specifically it is stated "Neglecting to poll the target audience for its opinions not only sacrifices the quality of the resulting platform but it also risks compromising its eventual acceptance" (Overbye, 2002 p35). The effort to include the controllers in designing the application resulted in a superior tool, immediately useful displays, and more enthusiastic response.

This is a particularly important aspect of the report (Overbye 2002), as it identifies the method used to solicit information from the controllers. In User-Centered Design (UCD) and indeed, in the whole of ergonomics and human factors, this is a fairly common approach. It is clearly stated that the approach used was not formal as it had been in previous instances in the past. Instead, an informal approach was opted for. This consisted of discussions where problems with existing displays were listed as well as a demonstration of various display options. The further pursuit of the project was justified because of the positive comments about the new display options. Once the new displays were created they were shown to the controllers over several days, this allowed for comments, suggestions and questions. The developer then went on to modify the application and the displays accordingly. This iterative, prototype approach, worked extremely well (Overbye 2002). Here we have a classic situation where display formats are presented and compared to the internal representations of the controllers involved. In this way an iterative process is developed without directly exploring the tacit domain.

The tacit domain remains elusive but almost within reach. Below is a summary of the controller's contributions in the form of suggestions and observations.

They are as follows (Overbye 2002):

- Be wary of clutter. Consider if the proposed display item adds new vital information. Can required information, presented in more than one ways, be accomplished without consuming additional display area?
- Adhere to the theme of the display. For example, when attempting to depict voltage profile information, avoid including other network elements such as transmission devices.
- Exclude complicated details where possible / appropriate. For example, individual busses in a sub-station are not required when power flow is the main objective of the display.
- Use colour to focus the user's attention, not monopolise it. For example, originally, high voltages were shown as red and low voltages as blue. This was counterintuitive for the controllers who were used to red depicting low voltages, as they are of greater concern to them.
- Respect the importance of time. A time stamp was used in the upper left corner of displays considered as real time displays, so as to be able to verify when the information displayed was captured.

All these recommendations allude to the tacit preferences and idiosyncrasies of controllers, but do not say so explicitly, and it is in this respect that this research aims to make a contribution by making explicit the tacit aspects of individual controllers preferences. Overall this last report appears to present the most significant and up to date efforts in design and implementation of visualization tools available in the USA at the time.

As far as the tacit domain goes, the above statements illustrate the controllers' ineptitude at describing what is going on in their minds, but that is possibly a question of training

(Lazanas 2007) or elicitation techniques. It is clear from the controllers' responses about clutter, adherence to the theme of the display, the request for exclusion of complicated details where possible / appropriate, the use of colour to focus the users attention and not monopolize it, and to respect the importance of time, etc., that they are directly referring to the tacit dimension against which they are comparing what was shown to them. This was implied however, as when they speak of clutter, they mean too much information organized in patterns, which do not match the tacit ones in their mind. Or when they speak of adherence to the theme of a display it may be implied that that external information which tends to dominate over the qualia arising in the minds of controllers (Ramachandran, 1997) is not such as to divert attention from the qualia already present in memories, which are weaker. The same applies when they speak of detail, colour, and time. The tacit dimension was therefore alluded to again, but only shown indirectly when the controllers expressed their preferences, which however remained undefined in their detail as a consequence of the absence of training on how to express their inner experience.

In a further paper Overbye (2008) presents some of the newer techniques, focusing on those that can improve operator situational awareness. The constant theme is that controllers need to be able to distinguish between what is going on in their mind instead of what is going on outside on the displays and to somehow put the two together. If this is not done then problems can occur.

As a summary, the prevailing conclusion appears to be that even though controllers are considered to play a major role in operating a transmission network the tacit factors, which either enable or inhibit their performance, remain invisible. As the list of what is regarded to be part of an electrical transmission network continues to expand to include a large variety of diverse aspects such as smart grids, economic dispatch, and independent power providers, controllers are still considered to stand apart from such a network in order to "control" it, and not to be an integral part, which they are. Experts from the cognitive sciences have commented on the need for information to be somehow presented in such a way that it "enters the heads" (Bainbridge 1968, p91-106) of the controllers, however it is still not known what controllers do with information *inside* their heads.

It is important to note that HMI developers who are not controllers and thus have alternative tacit representations of the network (Lazanas 2010) are designing the interfaces. In the instances where controllers are being consulted they seem to be incapable of describing what is going on inside their heads however this barrier has been overcome recently (Lazanas, 2007, 2010). Further, in many studies the new computer interfaces are being tested on non-experts. Students are often used to determine the usefulness of new HMIs, as mentioned in Overbye's papers (2000, 2002, 2008). In cases where the computer displays have been tested by expert controllers the internal representations of these experts are not noted. This could mean that if other experts have different preferences the displays will not meet their requirements. Most importantly the time during which decisions have to be made by the voltage desk controller under serious contingency conditions plays a major role in their ability to perform their work. The times involved for decision-making under contingency conditions are no more than 30 seconds, and under normal conditions no more than five minutes (Muller 2010). This clearly leaves no time for complex analytical decision-making when under such contingencies as many as 3000 alarms may be presented in various forms during a very short time. Clearly therefore, the hidden mental operations which make working under such conditions possible reign supreme, and must be investigated. All of the papers reviewed mention internal, representations, visualizations, or mental models and strategies that controllers use. Overall however, the tacit domain remains invisible in spite of the acknowledgement of its existence.

## 2.9 Review of the Cognitive Psychology and Emotions Theory Fields.

### 2.9.1 Cognition and the Tacit Domain

Having identified the numerous references to the tacit domain above, the literature review was expanded to include the field of cognitive psychology to find out what is current and accepted as far as theories about brain processing and mental operations go. This revealed

that the tacit domain is well understood and accepted in neuroscience and cognitive psychology. Please note that the theories presented below are presented in order to establish a solid theoretical base for the work that follows, and not in order to critique their validity, which is taken for granted as taught in mainstream curricula. To accomplish this, a number of sources were investigated including seminal works by Pinker (1999), Anderson (2002), Shalif (1987), Libet (2005), Ramachandran (1997), and Klein (1999). As mentioned at the start, the extensive referencing of textbook material is mainly for the sake of readers with an engineering background.

What emerged from this investigation was that it is well established that the human mind has layers, some conscious and others not (Pinker, 1999, Anderson, 2002, Libet, 2005, Ramachandran, 1997). The layers, which are other than conscious, support the operation of the conscious ones. It is the organization of these other than conscious layers that determine expertise under short time frames of response (Libet 2005, Anderson 2002). In this research we will attempt to unveil some of these subconscious layers and in so doing reveal some of the tacit elements of “expertise”. In general it was found that the sequence of events in performing a task are (Pinker 1999, p, Anderson 2002):

- The elements, which comprise an object, are identified from those around it.
- The object is recognized.
- It is then mentally manipulated.
- It is given meaning through association and its emotional significance identified.
- A sequence of actions is tacitly or consciously identified such as to achieve a desired objective with respect to it.
- The actions are performed and the result compared with the desired outcome.
- The process is repeated if required.

The ideas about the layers of the mind are not new. More than half a century ago Freud (McLeod 2009) postulated that the mind is divided into three parts: the conscious mind which contains all of the things a person is aware of in the present; the preconscious mind which contains all the memories and facts that can be recalled; and the unconscious mind

which remains hidden at all times. Freud believed the unconscious mind was the most important factor in directing behavior and personality. The reviews below are more up to date than some of his observations.

Pinker (1999, p 62) presents information very similar to that of Anderson (2002), when he states, “Intelligence then is the ability to attain goals in the face of obstacles by means of decisions based on rational (truth-obeying) rules.” The computer scientists Allen Newell and Herbert Simon expanded on this idea by noting that intelligence consists of specifying a goal, assessing the current situation to see how it differs from the goal (by tacitly assigning meaning to each element), and applying a set of (perceived as possible) operations that reduce the difference. We have desires, and we pursue them based on beliefs, which when all goes well, are at least approximately or probabilistically true (Pinker 1999, p 62). The term “beliefs” could be replaced by the term “mental models” or tacit representations. This statement captures in a nutshell what controllers do. Terms such as “signals”, “codes”, “representations”, “transformations”, and “processing” suffuse the language of neuroscience (Pinker 1999, p 83). Both Pinker (1999) and Anderson (2002) clearly state that a central agenda in psychology has been the discovery of the form of mental representations (the symbol inscriptions used by the mind) and the processes (the not so intelligent demons) that access (and process) them (Pinker 1999, p69). This is like Plato’s analogy of the cave, where the information in an internal representation is all that we CAN know about the world.

> *“Making the mental representations explicit is the route to rigor in psychology, and the way people generalize is perhaps the most telltale sign that the mind uses mental representations, and lots of them.” (Pinker 1999, p 85).*

In this research we want to make the tacit domain explicit, as we explore the layers upon layers of representations in the minds of the controllers, which underpin their expertise. Tacit representations also extend to physical actions, which engage muscles and limb movements that accomplish them. This is evident when we perform actions like driving a car that has an automatic transmission having got used to driving a manual one. The existence of such conditioning can explain how

controllers perform wrong actions when the *perceived* information on a HMI combines with pre-scripted motor patterns.

Looking back, Cognitive psychology (CP) began between 1950 and 1970 (Anderson 2002, p10) and it draws on information theory, artificial intelligence and linguistics. Information processing is the dominant approach in CP. This is illustrated by experiments that show increases in processing time as cognitive tasks become more complex. Brain mapping techniques have been used to identify which areas of the brain are involved in information processing. This is a complex approach as there are very many different dimensions to information processing. It is suggested that the brain operates by the aggregation of specialized parts that each play their own individual role in processing, by means of patterns of activation of neural elements, of aspects of incoming or self-generated information. This is what is known as PDP or Parallel Distributed Processing (Anderson 2002 p 32). This is similar to the statement made by Pinker (1999 p 140) where he states that, "while a person is consciously busy with something, parallel subconscious processing is going on at the same time, and that a person's mind is a set of agents nested into a hierarchy of subroutines with one at the top that hands over control to the fastest, loudest, or strongest agent, one level down", (Pinker 1999, p 144). In performing its function a controller's brain works in such a way as to first extract shapes from a visual scene and then having recognized the items extracted it proceeds to do something with them (Pinker 1999; Anderson 2002). In the case of a controller working through a contingency the case is made for him being modular, as one part assesses what went wrong, another decides where to get network support, another figures out how to maintain network stability, another performs the actions required on the HMI and yet another is determining the consequences of the actions performed (Pinker 1999, Anderson 2002).

An object therefore is a gestalt (Anderson 2002, p 44) of various segments of perceived information. Since the HMIs at the NCC have been changed we want to know how the gestalt (or tacit information) in a particular controller's mind responds to a given situation as presented on the new displays. This is because controllers can recognize incoming

visual information off the HMIs by template matching; feature analysis (recognizing features then combining them in a whole), and object recognition (identifying geons or sub-objects and putting them together) (Anderson 2002 p 51). Then the objects are further considered in terms of the context in which they appear. In the context of this research it is required to find out if even small changes in size between items displayed on the HMIs have had significant effect on some of the controllers' perceptions. It is also required to find out if when comparing the images on the HMIs with their internally generated references they found any discrepancies.

Laboratory tests have revealed that the human brain uses at least four major formats of representation (Pinker 1999, p89):

- "The first format is **the visual image**, which is like a template in a two dimensional picture-like mosaic.
- The second, is a **phonological representation**, a stretch of syllables that we play in our minds like a tape loop, planning out the mouth movements and imagining what the syllables sound like (in short term memory, i.e. repeating a telephone no). Phonological short-term memory lasts between one and five seconds and can hold four to seven "chunks" of auditory information (rather than just sounds).
- The third format, is **the grammatical representation**: nouns and verbs, phrases and clauses, stems and roots, phonemes and syllables all arranged into hierarchical trees.
- The fourth format is "**mentalese"**, the language of thought in which our conceptual knowledge is couched. This is how the traffic of information between mental modules flows that allows us to describe what we see, imagine what is described to us, carry out instructions and so on. This is evidenced by the fact that the information processing centres like the hippocampus (organizes long term memory) and frontal lobes (decision making) are not directly connected to the areas that process raw sensory input. They receive their input from other areas in the form of codes for objects, words, and other complex objects" (Pinker 1999, p 90).

The modular multi-format minds that we have (Pinker 1999, p91):

- “Modularise.
- Use sub routines.
- Each module does one thing well.
- Every module hides something.
- Localise input and output in subroutines.
- Choose the data representation that makes the program simple (Pinker 1999, p 91).
- Modular design is a characteristic of all complex systems like, bodies (organs), armies (divisions), books (chapters) etc.” (Pinker 1999, Anderson 2002).

A person’s conscious attention is likened to a spotlight, so that there is conscious serial attention. However this can go on together with unconscious parallel processing at a tacit level (Pinker 1999). A controller's mind is a group of agents nested into a hierarchy of sub routines where the one at the top hands over control to the fastest, loudest, or strongest one below (Pinker 1999). Seeing what is “out there” over our mental representations is quite rare for most of us. We see our ***versions*** of the objects in it (Pinker 1999). We have either a “visual field” (retinal frame) or a “visual world” (world-aligned frame) way of perceiving and we can switch between them (Pinker 1999 p 264).
The following sequence (Anderson 2002) illustrates what happens with such a model of perception.
Table 2.9.1.A: Processing steps in the process of cognition (Anderson 2002, p 73).

| | |
|---|---|
| Light Energy | |
| Primal sketch | Feature extraction |
| 2&1/2 D sketch | Depth information |
| 3D Sketch | Gestalt Feature combination |
| Recognition | Principles of organization & contextual information |

The controllers then further filter incoming information, attenuate it, or focus on it with or without eye movements. This has been particularly prominent with top-level experts who do not seem to focus on the HMIs initially, whereas the novices do (Lazanas 2010). This visual information can then be retained in a sensory memory briefly, where it is attended to (Anderson 2002, p 870). When elements of incoming information are similar (as they are between the ENCORE and TEMSE displays), distinctions take longer to make. Then the practice of control tasks allows for less conscious processing as various scenarios get rehearsed. This effect can work both ways; here, it was required to know, how long the controllers who were used to a particular type of display took to acclimatize to the new one. Finally, when processes become automatic, devoting attention to them is no longer necessary, and performance is no longer affected by the number of processes being performed simultaneously (Anderson 2002). This automatic processing effect can be dangerous as when the HMIs change controllers may find it easier to recognize patterns or objects, which they *expect to appear* (Anderson 2002). In the case of words the process is so automatic that it is very difficult not to read them automatically (Anderson 2002, p 100). This may lead to errors, as controller's minds may "read" non-existent information when they try to cope with different font sizes and other differences in the new TEMSE HMI. In this way what is regarded as "expected" by one controller may not be actually present in front of him.

Controllers can divide their attention and their efforts in varying proportions to attend to multiple tasks. When a controller is required to make responses in succession, the preceding one will delay the ones that follow. Tasks that do not require the same processing "equipment" such as visual or auditory, do not conflict during parallel processing (Anderson 2002). In this respect it was required to know how novices and experts process visual and auditory information against mental references. The brain is a complex parallel processing device operating at a tacit level and yielding results at the conscious level (Pinker 1999). The amount of time required to perform rotation or other visual manipulation of mental images is directly linked to the extent to which they are manipulated (Anderson 2002). In scanning a visual image there will be interference if simultaneous spatial processing of other information is required. This happens when a

controller has to scan the HMI while at the same time retrieving information, mentally, of how other parts of the network are, as the whole network is not displayed on the same screens. There is evidence that different areas of the brain are responsible for spatial and visual aspects of information (Anderson 2002). As visual images are not as easy to interpret as actual pictures of objects (Anderson 2002, p 122), it was required to find out if the controllers created images of the network in their mind, which looked like the geographical arrangement of the network (a more realistic representation), which does not appear on the HMIs. The construction of images in the mind happens by adding up the constituent parts or chunks of these images. The result of this is the arising of hierarchical organization of parts within parts (Anderson 2002). This seems to imply that images unfold, at a tacit level, as clustered files of information. In this study, it was required to know if the mental images of expert controllers unfolded to reveal more and more detail, and if under contingency conditions, their minds had the ability to manipulate the network images into simpler ones, for the sake of dealing with the plethora of information which appears, and which they have to deal with (Muller 2010).

The degree of retention of information is a function of how meaningfully, or to what depth, the information has been processed. Memories that are used often and that are recent are the easiest to retrieve (Anderson 2002). Memories are stored in networks of associations, and it is these associations regarding the ENCOR and TEMSE displays we wanted to reveal, for individual controllers. However the results of memory practice taper off according to a power rule (Anderson 2002). Elaborate processing of information (making use of multiple modalities) will result in better memory retention more so than just the intention to learn (Anderson 2002). This is a strong motivator for simulator training. Another example would be the use of color pens to draw out parts of the network in order to memorize its elements. “Schemas represent categorical knowledge according to a slot structure (materials: wood etc; shape: rectilinear etc. for house). Scripts are schemas used for events” (Anderson 2002, p 164). In this research it is required to see what were the scripts, by means of which, the controllers carried out the tasks given to them on the simulator. Schemas and hierarchies are used to recall learned material by inference (Anderson 2002, p 223), as learning and retrieval are context

sensitive as well as related to the feelings at the time of learning (Anderson 2002, p 229) (it's easy to recall happy memories when happy etc.). The fact that subjects can develop effective procedures for performing tasks without an ability to explain what they are doing (Anderson 2002) is an obstacle, which was overcome by the use of the NLP elicitation techniques (Lazanas 2007).

The essential elements of problem solving (Anderson 2002, p 237) are very similar to what Pinker presented, they are:

1. "Goal directedness. Goal state.
2. Sub goal decomposition. States along the way.
3. Operator application. An operator is an action that will transform the problem state into another problem state (different degree of solution) until the goal state is reached. Operators present different paths to the goal state. Operators can be acquired by discovery, analogy or example and instruction. Rules for problem solving have features such as conditionality (when to use the rule and what to do); modularity (particular rules for each action); goal factoring (each rule is relevant to a particular goal); and abstractness (each rule applies to a class of situations).
4. Means to ends analysis:
    - Directly getting to the goal and repeat state avoidance are used to select the actions that will lead to the goal state.
    - It is necessary to reason about sub-goal relationships in order to find the most efficient procedure of arriving at the final goal state.
    - Problem representation will affect the choice of actions to solve the problem.
    - A flexible approach to the use of objects facilitates creative problem solving.
    - People get set in their ways of problem solving as their preferred method of solution is reinforced. The opposite is true for arriving at creative solutions."

The above serve as general background information for engineering readers, and are very general statements, which are fine for theoretical modeling and undergraduate tuition. In this research, the tacit images and decisions, which appear spontaneously in the mental space of each individual, were investigated. Another issue is that some of the above statements deal with conscious processing and do not have direct relevance to the spontaneous (tacit) problem solving, which is demonstrated by experts in the field (Klein 1999).

Three stages of skill acquisition (Anderson 2002, p 273) are identified:

- "Cognition stage. A set of facts is committed to memory.
- Associative stage. Corrections are made in the initial facts and rules of performance and the time to perform the steps of the task is reduced. Facts and performance are mixed.
- Autonomous stage. The procedure becomes more automated and rapid. Speed and accuracy improve."

The autonomous stage was again the possible obstacle for those controllers who had extensive experience with the previous system, when the HMIs were changed at the NCC. This is because when a skill becomes obsolete (strategies used with ENCOR) people still tend to use the old shortcuts (Anderson 2002). In this research what will be investigated is how long individual controllers took to overcome the old habits of working with ENCOR, as the performance of a cognitive task shows modest decline after long retention periods, and how long it took controllers to create new autonomous behaviours as new autonomous performance of a cognitive skill tapers off with practice according to a power law.

Two types of knowledge (Anderson 2002, p 280) are identified; declarative (information) and procedural (actions). This seems to be one of the main areas of difference between the staff within the NCC and other sections in Eskom. In the NCC the emphasis is on

procedural knowledge, under severe pressure, and within very short time frames, while the system engineers and planners have days or weeks to perform their studies and think through their strategies. The process of conversion that controllers go through, between factual information to a set of actions that accomplish the goal is termed proceduralisation (Anderson 2002). At the NCC the first type of learning is tactical learning (Anderson 2002, p 283), which is a process where specific rules are learned for solving specific problems. This is followed by strategic learning (Anderson 2002, p 285), which implies developing or acquiring methods of organizing problem solving. This is first suited to a particular domain and then generalized as controllers move from control desk to control desk within the NCC. The ability to create new constructs for representing the key aspects of a problem is a sign of growing expertise (Anderson 2002). Another sign is the ability to recognize chunks in problems, which are patterns of elements that appear across different problem categories or that repeat over problems. The ability to store problem related information in long-term memory and to retrieve it increases with expertise. However it does not follow that expertise in one area will mean expertise in all areas (expert controllers may not be good general thinkers) even if the areas are similar, and it is worse for domains that are not similar. Here again, it is required to investigate how long it took (days, weeks, months) to get used to moving from ENCOR to TEMSE.

### 2.9.2 Mental Models

The Mental Model theory of Johnson – Laird (1978, 1983) (Anderson 2002, p 321) is mentioned and summarized in terms of how controllers create mental imagery to interpret and evaluate syllogisms. “People make decisions under uncertainty in terms of subjective utilities and subjective probabilities” (Anderson 2002, p 337). “The way by which the problem is framed influences the decision when there is uncertainty’ (Anderson 2002, p 340). “Success in the real world depends much more on deploying content-specific knowledge than on being able to correctly apply the rules of logic” (Anderson 2002, p 341), which is only possible when there is enough time for conscious processing. A distinction is drawn between a person’s ability to think better and to know better

(Anderson 2002, p 421), as the rate of information processing increases with development. Performance improves as we acquire more knowledge and more sophisticated strategies for applying it. Increased knowledge and maturity can compensate for decline in information processing speed (Anderson 2002). A distinction is drawn between crystallized intelligence (acquired knowledge) and fluid intelligence (ability to reason or problem solve in novel domains) (Anderson 2002, p 437). Controllers may be expert in spatial, verbal, visual or reasoning abilities, in this research it will be investigated how they tried to problem solve in their preferred way, making use of tacit strategies.

It seems that we can think of concepts for which we may have no words to describe. Yet language reflects the structure of how our minds process the world (Anderson 2002, p 363) and with a bit of training it is possible to create terms to describe previously unnamed experiences (Lazanas 2007). The acquisition and processing of language is independent from other cognitive systems according to the modularity view, which is also supported by Pinker (1999). The acquisition of the skill of describing tacit mental experiences was clearly demonstrated in previous research findings (Lazanas 2007), where controllers were soon able to “find” the words to describe the qualia rich (Ramachandran 1997) tacit imagery spontaneously arising in their minds. Imagination, particularly in visual form, is an alternative mode of mental processing that is far more useful in dealing with matters of the world out there. The decision making mode employed by the controllers can have a major impact on the outcome of their actions, as when in a particular context decisions that get processed visually yield the right answers, whereas other means of processing may not yield desired results (Pinker 1999). Einstein mentioned his ability to experience his theories rather than work them out. We all know the powerful effect of visualization or multisensualization on the body, as we experience physical symptoms due to our thinking (Pinker 1999). Space in the world is represented as space in the brain neural connections (Pinker 1999, p 287). It has been shown that holding a mental image can interfere with faint fine visual details of images on an HMI (Ramachandran 1997; and Perky effect, Nigel, 2010). The visual-motor coordination also suffers, this is particularly important when a controller performs the wrong action. When

controllers see some shapes and imagine others, later, they sometimes have trouble remembering which was which (Pinker 1999). This type of scenario takes place in post incident interviews at the NCC where controllers have difficulty accounting what actually happened (Muller 2010). The vivid mental images in controllers' minds can cause more activation of the visual cortex than the real images on the HMIs. Thus controllers run the risk of confusing imagination with reality. Ramachandran (1997) also discusses this effect, comparing the intensity of the qualia of the two representations (one from the world and the other internal).

**"The mind can zoom, shrink, pan, scan, trace, colour, etc**." (Pinker 1999, p 292). This statement in particular, has tremendous bearing on the current research. "Geniuses" like the experts at the NCC are not freaks they are like us, they spend over 10 years paying their dues (Pinker 1999). The sub-conscious structures of expertise and pre-existing pattern recognition models in the minds of Eskom experts are absent in the minds of novices who have not had time to create such structures. The latter, may have to make decisions through logical reasoning at a conscious level, which simply cannot process the plethora of inputs under contingency conditions (Miller 1956), within the time frames available.

### 2.9.3 Emotions

The triune brain (functionally the brain is considered as having three parts, reptilian, mammalian, and neo-cortex) works in tandem, not one part over the other (Pinker 1999). This brings us to the emotional domain (primarily the mammalian or limbic system) whose purpose is to focus mental activity, and which can be reprogrammed selectively (Pinker 1999). "**We register events as having an emotional significance** (Pinker 1999, p 143), which we seldom question, which then focuses the attention." To illustrate the importance of the powerful relationship between thought and emotions consider that the "amok" state is triggered by an idea (Pinker 1999, p 364). Everyone everywhere recognizes emotions like happiness, sadness, anger, fear, disgust, and surprise. Within the control room emotions triggered by events depicted on the HMIs may be a great

distinguishing factor of levels of expertise as experts may be able to deal with emotional reactions better than novices. In this research this will be investigated. Another aspect is that cultures differ in how they express emotions in public (Pinker 1999). This is particularly true in the NCC where people of different cultural backgrounds have to work together with some times detrimental consequences, as different levels of emotional expression can lead to misunderstandings (Muller 2010). '**The emotions are mechanisms that set the brain's highest level goals**, no sharp line divides thinking from feeling nor does thinking always precede feeling or vice versa" (Pinker 1999, p 373). The main calming agents in general are: predictability, allies within shouting distance, and a sense of competence and control. "We are happier when we are healthy, well fed, comfortable, safe, prosperous, knowledgeable, respected, non-celibate, and loved (Pinker 1999). When we are unhappy we work for the things that make us happy and when we are happy we attempt to keep the status quo" (Pinker 1999, p 389). As far as stress in the control room goes, it is enough to consider that we have twice as many negative emotions as we have positive and losses are more keenly felt than gains (Pinker 1999, p 391/2).

> ***"Our most ardent emotions are evoked by people*** *(Pinker 1999, p 396, Bridger 2007), and we have evolved keen emotion detectors of human states."*

All these factors come together to create the background conditions, which underpin the experiences and performance of the controllers within their particular shifts, at the NCC.

The review of the following material on emotions and their measurement is included because, during the preliminary interviews conducted with the ESKOM controllers, they repeatedly emphasised that the work they do has a very powerful emotional impact. This manifests as high stress levels that often cause them to resign or, in extreme cases, die prematurely (Muller 2010). **Shalif (1987, there are no page numbers in this document)** provides a convenient scale of measurement of emotional states, which was used to assess the emotions the controllers experienced. Emotional "states" represent the integration, within a person's body, of the impact of external stimuli as well as of the effects of *internal* representations and processing which the person undergoes during life

experiences (Shalif 1987). It was necessary therefore to pay special attention to the operation of the controllers' emotions during the interviews, as they revealed their overall response to their internal tacit interpretation of their work. This review is significant because it presents in a concise form a list of emotion by-poles from which, by combinations of any number of them, emotional states are created (Shalif 1987). By using this list, prevailing emotional states inside the network simulator room, under contingency conditions, were compared with the controllers' emotional experiences in the control room itself under similar conditions. Shalif was used as a reference for this research because he particularly emphasizes the tacit domain by means of "focusing" on emotions (Shalif 2004). In this way a person would focus their attention on a particular emotion progressively describing the tacit structure of the emotion and its sub-modalities (Bandler & MacDonald 1988).

Shalif states,

> *"The real motivation behind all human activity is emotional". He further states, "It is difficult for members of our culture – especially the more sane and serious of us – to come to terms with the fact that we are not really rational creatures" (Shalif 1987).*

He continues by pointing out that we are not really used to paying attention to or identifying our emotional states and those of others, even though we are always under their influence (Shalif 1987). Under the term "emotion" he includes moods, feelings, sensations, subjective experience, passions and the like, all being processes of the limbic system. These emotional processes can be triggered by receptors from any part of the body or even from internal brain operations. Shalif (1987) tentatively lists about 15 basic emotions each structured as a bi-polar continuum, mainly operating through the Limbic System in the centre of the brain. Lewis & Haviland-Jones (2004) emphasise eight while Ekman & Davidson (1994) lists between fifteen and seventeen in families or clusters. Ekman & Davidson (1994) state that there is agreement among researchers on the following:

- "There is information processing and evaluation of events that provoke an emotion.
- There are expressive and physiological changes that are to some extent distinctive for each emotion.
- There is retrieval of relevant memories expectations and methods for coping with the emotion-provoking event.
- Emotion involves a subjective experience, a feeling state, which may include awareness of some or all of these elements."

Ekman & Davidson (1994, p 412) also state,

> *"… emotion involves the whole of the organism. Emotional experience shapes and reflects individual personality development."*

Emotions serve a number of functions (no total agreement on all the items listed below or on their relative importance (Ekman & Davidson, 1994):

- "Emotions have motivational properties.
- Emotions organise behavioural and physiological patterns, high intensity emotions may disorganise behaviour.
- Emotional signals inform others.
- Emotional experience affects one's wellbeing and health."

There is disagreement about (Ekman & Davidson 1994):

- "How many emotions there are (there is agreement on five pan-cultural facial expressions for emotions: anger, fear, sadness, enjoyment, and disgust and disagreement on others like surprise, contempt, and shame /guilt.)
- What is the standard for what emotion has occurred

Finally they state, that generally, there are families of emotions each with sub divisions, which should be researched further" (Ekman & Davidson 1994).

Shalif's list of bi-polar emotion structures (1987) consists of:

- Contentment (Pleasure – Sorrow)
- Concern (Love – Hate)
- Security (Fear – Serenity)
- Play (Seriousness – Frolic)
- Belonging (Attachment – Solitude)
- Will Power (Volition – Surrender)
- Energy (Rigor – Flimsiness)
- Frustration (Anger – Leniency)
- Involvement (Interest – Boredom)
- Self Respect (Pride – Shame)
- Eminence (Superiority – Inferiority)
- Respect (Adoration – Scorn)
- Vigilance (Wariness – Dreaminess)
- Expectancy (Surprise – Routine)
- Attraction (Disgust – Desire)

The above list is not exhaustive as there is ongoing research to identify further categories (Shalif 1987). These basic emotions contribute to and combine with each other (as different ones are evoked along their bipolar continuum) resulting in an almost infinite range of "states". This list was used to identify trends and similarities between the emotions of individual controllers in the simulator and control rooms, and not to pin down exact emotions. Advanced bipolar types of biological structures produce the basic emotions. These structures operate much like opposing vectors, with contradictory neurological subsystems. They are active all the time; this allows them to respond faster and to less powerful influences than unipolar structures of a more primitive kind (Shalif 1987). In this way one sub-system is triggered and tends to create the emotion at one end of the bipolar continuum while the other sub-system does the opposite. In this way, as all the various sub systems are triggered, the overall combination is experienced as an

emotional “state” (Shalif 1987). Each of the basic emotions contributes in two ways towards the overall state. That is, by the quality of the prominent point on the emotion’s bipolar continuum as well as its intensity.

The emotions with greater survival value are experienced more often and with higher intensity. This is particularly significant in the national control centre environment as the consequences of incorrect operations can have tremendous impact on the country as a whole, and as result produce intensely stressful states (Muller 2010) within the controllers. Fluctuations between emotional states, resulting from complex situations within a particular shift, represent another way that emotions can hamper or support a controllers’ performance, as relationships within shifts vary. “Emotions are communicated and registered non-verbally, even when we are lost for words to describe them, by means of tonality, facial expression and body posture. In general, an emotional state lasts up to 10 seconds in its original state. However when the homeostasis control mechanisms fail it can last up to a whole hour or more” (Shalif 1987).

The purpose of the emotional experience as defined above has 10 main facets (Shalif 1987):

1. “When intense **it concentrates the attention** and other resources of the individual to deal with emergencies.
2. **It labels** the various happenings in order to facilitate their integration and further processing by other sub systems as well as to bring about modifications in the processing subsystems themselves.
3. When it is enduring (moods) it acts as a **reminder** or verdict about life as such.
4. It labels experiences and their constituents in **comparison** to other versions of the same from past and future.
5. It helps to demarcate the short and long term aspirations of an individual.
6. Its most prominent function is to **attract the attention from other** ongoing activities.
7. It can, when it changes sharply, abruptly **transform the whole state of mind**.

8. When it has strength, lasts long, or has the appropriate quality it **dominates the awareness** and prevents one from forgetting.
9. When not so intense it acts as a herald, making “important announcements” prompting one to action.
10. It is the means by which the genetic apparatus directs us **to survive**. In this respect the emotional sub system and the experiences it creates may be the only motivation system of the individual.”

“We are not programmed by our nature or by our upbringing to do specific things in a specific manner. What we are really shaped into is to feel certain things in certain circumstances, to strive to keep the emotional experience within specific boundaries and to acquire proficiencies and shortcuts that help us to achieve this aim” (Shalif 1987). This means that we are not directed to achieve specific aims but to preferring certain emotional qualities. This last statement seems to expand on Newell and Simon’s statement (Pinker 1999) by emphasizing the emotional focus of motivation. Our main survival programs are not intended to achieve specific conditions and perform specific acts, but to achieve more flexible and "abstract" targets of emotional experiences. The best means for this mission is the ability to improvise, based on the plethora of emotional supra-programs built and improved during life (Shalif 1987). In conclusion here is a quote from Pinker (1999, p 424), “The mind has many parts some designed for virtue, some for reason, some clever enough to outwit the parts that are neither. One “self” may deceive another but every now and then a third “self” sees the truth.”

### 2.9.4 Qualia

Continuing our journey further towards the tacit domain we encounter the concept of qualia. **Qualia are the individual components of mental experience (i.e. the redness of red, the squareness of square, etc.)** (Ramachandran 1997). The qualia concept is pertinent to this research because it is very similar to the concept of sub-modalities as used in the NLP field (Bandler & Macdonald, 1988). With the current research we aim to identify the qualia aspects of human expertise, which remain tacit, yet as pointed out

below, are a fundamental distinguishing factor between tacit experience and rationalization. Rationalizations, such as a person's opinions or beliefs about a situation, do not have qualia associated with them (Ramachandran 1997), and it is **in this way that we can distinguish between what is tacit visualisation and what is not**. This is the key to navigating the tacit world by means of the NLP elicitation techniques (Bandler & Macdonald, 1988). Ramachandran (1997 p 1) states,

> *"Neurological syndromes in which consciousness seems to malfunction, such as temporal lobe epilepsy, visual scotomas, Charles Bonnet syndrome, and synaesthesia offer valuable clues about the normal functions of consciousness and 'qualia'. An investigation into these syndromes reveals, we argue, that qualia are different from other brain states in that they possess three functional characteristics, which we state in the form of 'three laws of qualia' based on a loose analogy with Newton's three laws of classical mechanics"*.

The three "laws" are (Ramachandran, 1997):

- "First, they are irrevocable: One cannot simply decide to start seeing the sunset as green, or feel pain as if it were an itch;

- Second, qualia do not always produce the same behavior: given a set of qualia, we can choose from a potentially infinite set of possible behaviors to execute; and

- Third, qualia endure in short-term memory, as opposed to non-conscious brain states involved in the online guidance of behavior in real time."

It is suggested that qualia have evolved these and other attributes because of their role in facilitating non-automatic, decision-based action. This is consistent with the Crick-Koch view that the neurons, which project to the frontal lobes, are the qualia neurons because, obviously, the frontal lobes are important for the execution of choices. It could be argued, however, that what people think of as the choice itself is really the work of a limbic executive system consisting of the amygdala, anterior cingulate cortex, and other areas,

and that the frontal lobes are needed only for fully working out the long-range implications and possible alternatives which the decision entails, and for dealing with complications arising as the decision is executed" (Ramachandran 1997). This is what takes place in the minds of controllers as they react to contingencies with deep emotional experiences. With these statements Ramachandran captures the gist of what controller's brains do at a deeper neurological level than discussed by the previous authors. Now, from this it can be concluded that as controllers respond to contingencies represented by images on the HMIs and they at the same time run a "virtual reality" simulation in their mind, using the less vivid qualia generated from memory, they have to distinguish between the two in order to make appropriate decisions. This is going on while strong emotions govern their responses (Shalif 1987; Ramachandran 1997). The memories that are normally evoked in this case are not fully laden with qualia; they have qualia, which are just vivid enough to allow them to run the simulation. If they possessed full-strength qualia that would be dangerous as it would be difficult for them to distinguish between reality out there and their mental images (Ramachandran 1997), as they would not have any way of distinguishing between the two. This can take place when the intensity of the two reaches similar levels as in the Perky effect (Nigel, 2010) when internal representations begin to influence the perception of external information from HMIs.

Further, the qualia difference between what a person experiences and the qualia of their rationalizations or beliefs are associated with 'partial qualia' and conscious awareness, once they are made explicit in 'working memory'. "In the absence of sensory support, however, the qualia associated with beliefs are fleeting and less robust than the real qualia-laden percepts associated with sensory stimuli. Therefore the distinction between qualia associated with percepts and those associated with explicit beliefs may be quantitative rather than qualitative. **Tacit beliefs are completely qualia-free"** (Ramachandran 1997). This is a very significant statement for this research as we focus on the TRVPs of the controllers' tacit experience, and not what they rationalize is going on, or should be done. In other words **if they are not mentally experiencing something they will not be able to report about its qualia content,** as would be the case with beliefs. Rationalisations and speculations were completely avoided while eliciting TRVPs

by insisting that the controllers report what they mentally see, hear, and feel at every stage of the interview. To summarise, controllers go through the following sequence of events as they perceive reality, they Sense, Image, Feel and Think (SIFT, Siegel, 2007) their way as they work. However all they experience are the qualia associated with each one of these stages. In this research the qualia associated with the second stage, “Image” will be investigated. Ramachandran has been criticised for his use of qualia with respect to the concept of the self and subjective consciousness, and the fact that he holds that at some point in the future it will be possible to register the qalia in one persons brain in the brain of another (Rockets 2005). For many scientists this last point is not so important because, at least theoretically, the entire process of experiencing the colour blue can be physically mapped in the brain of one person and by doing so science need prove nothing else to do with consciousness or the sense of self (Rockets 2005). These arguments do not impact on this research however, as here, the concept of self, self-awareness as the last frontier in science, and the brain elements responsible for it, are not in question.

### 2.9.5 Conscious Processing Delays

Going even further into the tacit domain we now come to the work of another significant contributor to the field of neuroscience. Libet (2005) presents the “famous” summary of his findings, which effectively shows that any conscious processing of information is about 0.5 sec behind (in time) the subconscious and unconscious processes, which underlie it. This implies that unless a person is involved in deliberate conscious decision making, what drives their decisions are subconscious processes of which they have no awareness. This is in spite of the fact that they will later say, “I decided”, about what they did. What Libet showed is that the “I decided” statement is not correct in short time frames. It is an entirely different matter when a person can go through information slowly and analytically in order to decide about something, and even then the debate goes on as there is no clear point where the subconscious forces stop acting. In the control room environment when contingencies occur it is not possible to consciously and slowly decide, when there are hundreds of competing bits of information requiring attention in the form of alarms (as many as 3000, Muller 2010), images, other people talking, etc. All

the more then is the need to identify the elements of the tacit experiences which are on the borderline of conscious awareness, because in short time frames that is where decisions are made, by non-analytical processes.

### 2.9.6 Naturalistic Decision Making

Finally to bring all these ideas back to the practical world of engineering, we consider the work of another significant contributor to our understanding of how experts behave in real world situations. This is Klein, and the Naturalistic Decision Making model (Zsambok and Klein 1997). Klein's work has expanded our understanding of the decision making processes, which take place in the minds of experts who work in real industrial or other similar practical situations (Zsambok & Klein 1997 and Klein, 1999). By pointing out that traditional models of decision making do not take into account many critical aspects of operational settings (Klein, 1999), he brings our attention to the fact that what goes on in the real working world is not the same as what many believe. Decision makers in operational settings are usually very experienced, in contrast to subjects used in laboratory studies. Klein makes it clear that there are significant differences between real experts and naïve subjects used in laboratory studies.

According to Klein (1997, 1999) controllers, like those in the NCC, use a recognitional model (Recognition-Primed Decision-Making model or RPD) of decision-making that shows how experience can be used to avoid some of the limitations of analytical strategies. This model explains how controllers can make decisions without having to compare options. It fuses two processes, situation assessment, and mental simulation, and asserts that they use situation assessment to generate a plausible course of action and use mental simulation to evaluate that course of action. Klein concludes (1997) that the RPD model describes how decision-making is usually carried out in real world settings. This conclusion is based on a series of studies (Klein 1997) in which it was found that recognitional decision making is much more common than analytical decision making. The strengths and weaknesses of recognitional and analytical decision strategies are contrasted to show that recognitional decision-making is more likely when the decision

maker is experienced, when time pressure is greater, and when conditions are less stable; which is what happens at the Eskom NCC (Muller 2010). In contrast, analytical decision-making seems to prevail when the available data are abstract and alphanumeric rather than perceptual, when the problems are very combinatorial, when there is a dispute between different constituencies, and when there is a strong requirement to justify the course of action chosen. He goes on to say that, "the RPD process approach should not be taught, since the RPD model is already a description of what people do. Instead, training is needed in recognizing situations, in communicating situation assessment, and in acquiring the experience to conduct mental simulations of options" (Klein 1999). This area of recognitional/RPD decision-making is what this research will be expanding on by investigating its tacit components.

However, even here where the tacit domain, as defined earlier, is directly referred to by means of using the term recognitional and therefore assuming a comparison between tacit and external information, very limited information about its qualia content and structure is given. The RPD model is most suited in situations where fast decisions are made by experts who have internal representations of similar situations and not novices who don't. In this research the content and structure of some of the tacit processes, which underpin the RPD model will be revealed, which is the contribution of this work to the field. This will be done both in terms of findings as well as elicitation techniques. This research will try to confirm Klein's statements by revealing in detail the tacit content and structure of the mental representations, which exist in experts' (Eskom controllers) minds. In so doing what their expertise consists of, will be revealed to a considerable extent. These findings can then be used to transfer the tacit aspects of expertise to others (novices) by training (not information transfer).

It can be said from all the material reviewed above that human expertise has structure (specialized areas of the brain/mind have developed for specific functions) as well as content (the particular mental representations of the word "out there"). The content and the structures which controllers' minds use are stratified in "layers" some of which are outside awareness. For short time frames these subconscious and unconscious layers are

more important than conscious processes, and are driven by emotional motivators. It is some of these layers of mental representation that this research has sought to reveal, as will be presented in the Findings section. Finally it is possible to distinguish between rationalizations and tacit experience on the basis of the qualia content of the descriptions provided.

## 2.10 Knowledge Elicitation Techniques: Retrospective Verbal Protocol Analysis (RVPA).

In this section we will consider the methods that can be used to elicit the tacit part of experience, such as Verbal Protocol (VP) analysis and Retrospective Verbal Protocol (RVP) analysis. Verbal protocols are recorded sequences of what controllers do as they verbally describe what they are doing while they are doing it. Retrospective Verbal protocols are recorded sequences of what controllers say they did after they have done it. Out of a variety of possible elicitation approaches the second one in particular, is the most appropriate for our purposes (Thatcher 1995). A modified version of RVP will be used in this research called Tacit Retrospective Verbal Protocol analysis (TRVP), as this approach extends the scope of RVP to include the tacit facets of the controllers' experience. This extension is made possible by including the Metamodel (Grinder and Bandler 1975) and sub-modality elicitation techniques (Bandler and Macdonald 1988), as will be shown later. Again note that the extensive referencing of standard theory is for engineering readers and is not intended to tax audiences with a psychological background. Also, other than the comments about the absence of the inclusion of tacit factors, there is no intention to critique the theories presented other than to include comments from others who have (Thatcher 1995).

### 2.10.1 Background

What follows is a brief overview of the aims of Human Factors Engineering, Experimental Psychology, and Engineering Psychology. This is done in order to show that Engineering Psychology's purpose is to take into account the human in order to

produce better designs. Wickens (2000) takes an in depth look at these areas of research in which the tacit domain is often mentioned. However there is only some limited description of structure and no evidence of actual detail regarding tacit content. Here are some highlights from Wickens' work. "Designing machines to accommodate the limits of the human user is the concern of the field called Human Factors. Meister (1989) defines human factors as,

> *"The study of how humans accomplish work-related tasks in the context of human-machine system operation, and how behavioural and nonbehavioral variables affect that accomplishment" (Wickens 2000, p 2).*
>
> *"The fundamental goal of Human Factors engineering is to reduce error, increase productivity, and enhance safety and comfort when the human interacts with a system. The goal of experimental psychology is to uncover the laws of behaviour through experiments. Engineering psychology arises from the intersection of these two domains. The aim of engineering psychology is not simply to compare two possible designs for a piece of equipment (which is the role of human factors), but to specify the capacities and limitations of the human (generate an experimental data base) from which the choice of a better design should be directly deducible" (Poulton, 1966, Wickens 2000, p.178).*

"That is, although research topics in engineering psychology are selected because of applied needs, the research goes beyond specific one-time applications and has the broader objective of providing a usable theory of human performance. (Wikens 2000, p 3)". This is a statement, which illustrates the fundamental difference between this research and the general trend in Engineering Psychology. In this research the individual components of spontaneously arising tacit experiences (qualia), for a particular individual, doing a particular job, under particular circumstances, will be investigated. In the field of Engineering Psychology, as stated above, generalized theories of human behaviour are created. "Before the birth of human factors, or ergonomics, in World War II, emphasis was placed on designing the human to fit the machine. That is, the emphasis was on training. Experience in

World War II, however, revealed situations in which systems with well-trained operators weren't working. As a result, experimental psychologists from both sides of the Atlantic were brought in to analyze the operator-machine interface, to diagnose what was wrong, and to recommend solutions (Fitts & Jones, 1947; Mackworth, 1950). This represented the practical need underlying the origin of human factors engineering." (Wikens 2000, p3). The following research methods are categorized as relevant or not by Wickens (2000).

Table 2.10.1.A: Research Methodologies (Wickens 2000, p7)

| **Research Methodologies** | **Design Relevance** |
|---|---|
| 1. Field Studies | High |
| 2. Accident/Incident Reports | |
| 3. Surveys | |
| 4. Task Simulations | Medium / High |
| 5. Laboratory Experiments | Lower |
| 6. Literature (research and handbooks) | |
| 7. Models (human simulations) | |

The first five methodologies presented in the table above, depend to some extent on extracting specific measures of performance or behavior from the user. Generally such measures can be associated with one of four categories of raw data (Wickens 2000, p 9):

- "Measures of speed or time: How long does it take to estimate one's position on an electronic map?
- Measures of accuracy or error: What is the probability of a correct data entry string on the computer? How much does a driver deviate from the center of the highway as she tries to use a cellular phone?
- Measures of workload or capacity demands: How difficult, on a scale of 1-7, is it to use the product?
- Measures of preference: Does the operator prefer the electronic map over a paper map, or use the rotating more than the fixed version of the former?"

Even though this is a review of a text book for undergraduate tuition and therefore too general for critiquing the whole of engineering psychology, it is clear that the emphasis lies on mainly explicit information processing, and again no consideration is given to the tacit domain other than in the last category where mention of preference is made. In the model below (Wickens, 2000) a useful framework for analyzing the different psychological processes used in interacting with systems and for carrying out a task analysis is provided. Two overall properties of the model are apparent. First, information processing is represented as a series of stages, whose function is to transform or carry out some other operation on the information. Second, the presence of a feedback loop suggests that there is no fixed starting point in the sequence of processing operations. Processing may start by an environmental input, or it may start by the operator's voluntary intention to act, initiated somewhere in the middle of the sequence (Wickens, 2000). The stages of the Model Of Human Information Processing from Wickens (2000, p 10) are:

**"Sensory Processing:** Information and events in the environment must gain access to the brain. Properties of both our visual and auditory receptors (as well as those of the other senses) have a tremendous impact on the quality of information that reaches the brain. However, all sensory systems have an associated short-term sensory store (STSS) that resides within the brain. This is a temporary storage of the raw stimulus with durations as short as around one half second (visual STSS), to as long as 2-4 seconds.
Here sub-modality references are made (as in someone hearing some words) but no mention is made about the content (i.e. the voice, timbre, orientation, etc.) thus the content of the tacit domain is not considered."

**"Perception:** Sensory processing is necessary but not sufficient for effective human performance. Raw sensory data relayed to the brain (and perhaps preserved in a sensory store) must be interpreted, or given meaning, through the stage of perception. It is the role of perception to decode this meaning from the raw sensory data. Perceptual processing has two important features. First, it generally proceeds automatically and rapidly (requiring little attention). Second, it is driven both by sensory input (which we call

bottom-up processing) and by inputs from long-term memory about what events are expected (which we call top-down processing). These are the tacit representations, which drive behaviour. The speed and relative automaticity of perception is what distinguishes it from the cognitive processes, which take longer, as discussed below. Of course the distinction between perceptual and cognitive operations is not always clear-cut; the two represent endpoints on a continuum. Perception is partially determined by an analysis of the stimulus or environmental input, relayed from the sensory receptors by the sensory or "lower" channels of neural information. Hence, this aspect of processing is often termed bottom-up perceptual processing. However, when sensory evidence is poor, perception may be driven heavily by our expectations based on past experience, an influence known as top-down processing (Rumelhart, 1977). These are the two conflicting trends when the controllers at the NCC had to work on the new TEMSE HMIs when they had been conditioned to use the old ENCOR system. This past experience is stored in long-term memory. Bottom-up and top-down processing usually work harmoniously together, supporting rapid and accurate perceptual work. However, sometimes unfamiliar circumstances remove the ability to use past experience, leading bottom-up processing to do nearly all the work as in the case when TEMSE was first introduced. Alternatively, poor sensory quality sometimes forces the perceiver to use top-down expectancies. If such expectancies are wrong, perceptual errors can occur. These statements speak directly to the aims of this research. They show how experts sometimes recognize how a situation is and act, or run scenarios in their minds and act, or sometimes see the wrong thing altogether and perform the wrong action when the self awareness part of the processing loop is not activated. Also in the cases of novices the absence of top-down LTM information creates stressful feelings, which result in poor performance."

**"Cognition and Memory:** As we noted above, the boundary between perception and cognition is sometimes blurred because both may provide similar implications for action. However, the important distinction is that cognitive operations generally require greater time, mental effort, or attention. This is because such cognitive operations as rehearsal, reasoning, or image transformation are carried out by using what is called working memory (Baddeley, 1986), a vulnerable, temporary store of activated information. The

key features of all of these operations are that they are conscious activities, which transform or retain information, and that they are resource limited (Norman & Bobrow, 1975). That is, each is highly vulnerable to disruption when attentional resources are diverted to other mental activities. Sometimes material that is rehearsed in working memory can get access to a memory system that is less vulnerable, and hence more permanent: long-term memory. As we have discussed above, learning about the properties of information in an environment forms the basis for expectancies that drive top-down perceptual processing. Again this is relevant to this research, because when the time for conscious processing is limited and when the subject is fatigued or frightened there is quite a bit of strain as the various processes mentioned above conflict. If the tacit aspects of memory (spontaneously arising images and strategies) are not sufficient to carry out the required operations, and there is no time to consciously analyze information within the time frames available, the controllers manifest expressions of frustration and poor performance."

**"Response, Selection, and Execution**: The understanding of a situation, achieved through perception and augmented by cognitive transformations, often triggers an action—the selection of a response. The selection of a response or choice of an action is quite distinct from its execution; the latter requiring the coordination of the muscles for controlled motion, to assure that the chosen goal is correctly obtained."

**"Feedback:** The feedback loop of the model indicates that the human may directly sense actions or, if those actions influence the system with which the human is interacting, their consequences will be observable sooner or later. The presence of the feedback loop has two implications. First, its presence emphasizes that the "flow" of information can be initiated at any point. Thus, a driver's decision to turn on the radio is not driven by a perceived environmental event, but rather by a cognitive motivation to obtain information or music. Interestingly enough, no mention is made here as to what internal factors prompted that need. The feedback loop is important for establishing that the intended goal was achieved. Second, the feedback loop emphasizes that in many real-world tasks, such as driving, walking, or navigating through a computer information database, the

flow of information is continuous; thus, it is just as appropriate to say that “action causes perception” as it is to say that perception causes action (Powers, 1973; Neisser, 1976). A critical factor that influences the extent of this closed-loop interactivity is the delay of the system in responding to human actions. For controllers working with an HMI this delay is typically short. The controller perceives the change caused, by say, opening a breaker, and hence, special properties of closed-loop dynamic systems must be considered in examining human performance. However, for some actions like the controller’s decision to follow the advice of a senior staff member to take into account prevailing conditions elsewhere, like veld fires etc., it may be several minutes before the implications of that decision are realized. Hence, human performance with the senior advising can be analyzed with less concern for the feedback loop. Although the controller’s learning about the reliability of the senior’s advice will depend very much on this delayed loop.”

**“Attention:** A final property or component of the model is attention. Many mental operations are not carried out automatically but require the selective application of these limited resources (Kahneman, 1973; Pashler, 1998), like vision, which can be (through eye movements) directed to different channels in the environment, or top-down perceptual process (scanning processes are often driven by past experience), knowing where to look when. But this experience may also be the cause of errors as the internal drivers of knowing where to look are tacit and often out of date as was the case at the NCC. The selective application of limited attentional resources is much broader than its application to scanning. Indeed, when the controller has many tasks to perform he must select a strategy for dividing attention or allocating resources between these different tasks or mental operations (Gopher, 1993; Kahneman, 1973). When the total attention demand of these tasks is excessive, one task or the other must suffer. So, for example, if the controller becomes preoccupied with planning what equipment to energize to prevent a voltage collapse, or diagnosing the cause of a voltage dip, he may still fail to detect the information on the HMI, even if his eyes are looking forward.”

“The model described above for human information processing is not a computational one that can provide estimates, say, of the time required to perform certain tasks, or the

error rates expected. Rather, it provides a general framework for analyzing human performance. The structure of the model suggests that its components can be studied and analyzed independently from others. In the context of this research the elements of **Perception, Cognition and Memory Response, Selection, and Execution** were considered. For example, the limited capacity of working memory will have similar design implications, whether the controller must take action on its contents using vocal commands, key presses, or manipulations of a mouse." (Wikens 2000, p14)

Further, the verbal-phonetic and visual-spatial codes of working memory appear to function more cooperatively than competitively. One implication of this cooperation is that the two codes do not compete for the same limited processing resources or attention. That is, if two tasks employ different working memory codes, they will be time-shared more efficiently than if they share a common code. There are two forms of working memory, each processes or retains qualitatively different kinds of information (spatial and visual versus verbal and phonetic), and each can be disrupted by different concurrent activities. "Therefore, tasks should be designed so that this disruption does not occur. Tasks that impose high loads on spatial working memory (e.g. working on the HMIs) should not be performed concurrently with other tasks that also use the spatial working memory resources. Spatial tasks are less disrupted by employment of the phonological loop to handle subsidiary information-processing tasks (Liu & Wickens, 1992; Wickens & Liu, 1988, Anderson 2002). Correspondingly, tasks involving heavy demands on verbal working memory, such as editing texts, computing numbers, and using symbolic-based computers, are more disrupted by concurrent voice input and output than by visio-spatial interaction (e.g., control with a mouse)" (Wikens 2000, p244). All this takes place with the limits set by Miller (1956) of $7 \pm 2$ chunks of information. Miller (1956) showed that the capacity of working memory is $7 \pm 2$ chunks of information. "A chunk is a set of adjacent stimulus units tied together by associations in the subject's long-term memory" Wikens 2000, p 251). Thus, seven words or chunks, define the capacity of working memory, even though this represents more than seven letters, because the words are each familiar sequences to the subject experienced together, so the letters within each word are stored together in long-term memory.

From all the above, it is evident that the tacit domain is referred to again and again without providing any direct means to access it. However these structure references, as generalized models, can serve as a basis for our investigation as we endeavour to reveal the underlying tacit sequences in a particular individual, while performing a particular task. In order to do this a method of elicitation of the tacit experience of individual controllers needs to be identified. As will be shown below the best candidate found for this job in the field of Engineering Psychology is the use of Verbal Protocols (VPs) and Retrospective Verbal Protocols (RVPs) (Thatcher 1995). However even these were not found to be adequate for this research and thus the Tacit Retrospective Verbal Protocol (TRVP) was created.

Thatcher (1995) makes use of VP analysis in a similar scenario, that of a power station (Matimba), boiler control room. He states that "since it is not possible to observe the cognitive activity of human operators one must use indirect qualitative task analysis methods to ascertain the inner workings of controllers' minds" (Thatcher 1995, pii). To state "it is not possible", may create a sort of an invisible mental barrier, which the current research will try to overcome by asking the controllers themselves to observe the tacit phenomena as they arise in their individual minds and report on them.

### 2.10.2 Methods of Elicitation

Some parts of Thatcher's work have been included here because of their similarities with this research, particularly the issues regarding Verbal Protocol analysis and its suitability. In the initial section of his dissertation he goes on to identify a number of data gathering, and data analyzing techniques that can be used to determine aspects of the workings of controllers' minds. The method he used to do his research was selected after evaluating and comparing a variety of options that are listed below. VP analysis allows researchers to obtain data about many cognitive processes. These could be about data on problem solving, fault diagnosis, mental models, and diagnostic judgment. The emphasis of his study was on on-the-job performance, problem solving strategies, and cognitive

ergonomics, all underpinned by internal representations, which are not made explicit even though their existence is acknowledged.

The Cognitive Task analysis methods considered by Thatcher (1995) are summarized below:

**Human Error Analysis.**

This is a method of gathering data about human information processing. It is deemed to not have a strong theoretical basis. The method is limited by inconsistencies in categorization and has limited application to cognitive processing that results in human error.

**Cognitive Modeling (Thatcher 1995, p 26).**

In this category the GOMS model by Card, Moran, and Newell (1980) and extended GOMS model of Arend (1991) are quite significant. Other methods are Command Language Grammar (CLG) of Moran, the TAG model of Payne and Green, the Cognitive Complexity Theory (CCT) of Kieras and Polson, Task Analysis for Knowledge Description (TAKD) of Diaper and Johnson and Sundstorm's Functional Information and Knowledge Acquisition (FIKA) (Thatcher). All these methods are inappropriate since they focus on the performance of tasks and they assume that users have well developed plans and perfect knowledge of available actions.

**Hierarchical Task Analysis (Thatcher 1995, p 28).**

This is a method that makes use of task analysis into tree-like structures of goals and sub goals, as well as operations and sub-operations used for the identification of ergonomic problems. It is not suitable for the elicitation of mental models. Its advantage over cognitive modeling techniques is that semi or un-structured interviews are used to elicit information from actual operators of systems. What is required is an improved form of empirical data gathering.

**Simulation Modeling (Thatcher 1995, p29).**

This is of no use to this work at this stage as the method consists of creating computer-simulated models of human mental operations and presenting these computer models with problem scenarios to the controllers, which they have to resolve.

**Cognitive Walk Through (Thatcher 1995, p30).**

This technique does not involve the operator and it is used by developers to validate their user interface designs, by "walking through" them as if they were the operators.

**Eye Movement Analysis (Thatcher 1995, p30).**

This technique uses analysis of eye movements as an indicator of where the operator obtains information. To achieve this, infrared reflectrometry and eye tracking (electro-oculograms) are used. From such data, information about the way that operators move their attention is obtained and from that the mental models that they use can be inferred. However the emphasis is mainly on performance of tasks and not on the tacit visualizations of the operators. There is merit in recording eye movements and using the information as a platform to ask questions about tacit processing of the controllers.

The following elicitation techniques were considered:

**Discourse Analysis (Thatcher 1995, p33).**

A number of methods have been used to elicit information from experts. These are questionnaires, interviews, and protocol analysis.

**Questionnaire** Analysis (Thatcher 1995, p33).

This involves "what and how" questions as well as drawing maps of task descriptions. This technique relies on conscious process feedback and is therefore not suitable for the elicitation of metaphors and tacit visualizations.

**Structured interviews (Thatcher 1995, p33).**

Semi-structured and open-ended interviews can be used for obtaining cognitive information from controllers of complex systems. From these the semi-structured and open-ended approach is suited to this work as even "make believe" situations and responses can be considered. These interviews can take place before or after the completion of a task. A criticism of this approach is that only information about what is verbally explicit is provided. A special category of structured interviews is verbal protocol analysis.

**Verbal Protocol Analysis (VPA) (Thatcher 1995, p35;** Ericson & Simon, 1993).

Verbal Protocol Analysis is the most widely utilized method for cognitive task analysis. It consists of subjects “thinking aloud” their thought processes about a task while it is being carried out or even afterwards. It is stated that when subjects report their experiences after the event it is not as reliable given that memory plays a role. Verbal protocols can be recorded during the performance of a task or retrospectively. The problem of memory lapse during retrospective protocol elicitation can be minimised with the use of video recording of the controllers while performing their tasks in real work environments (Thatcher 1995). This is the approach taken for this research, where controllers were shown a playback of themselves working on the network simulator prior to the interview process.

It is important to note that cognitive styles stabilize by eight years of age and cognitive functioning declines with age (Thatcher 1995). This includes information processing preferences, preferred mode of perceiving, thinking, problem solving, remembering, preferences in the mode (s) of perceptual organisation, and the conceptual categorisations that individuals use. From the above it can be concluded that systems need to be adaptable to the user’s preferences, abilities, and styles and not the other way around, and it is a clear acknowledgement that the tacit domain must be acknowledged in HMI designs.

As far as VPs are concerned, since 1987 there has been a return to verbal protocol analysis as a more modern form of introspection (Thatcher, 1995, p 35). Ericsson and Simon (1993) developed a comprehensive methodology of VPA. Verbal protocols have been used by Hegarty et al (1988), Kieras and Bovair (1988), Sasse (1991), to look at cognitive functioning in complex process control tasks and to obtain information about controllers' mental models (Thatcher 1995, p 38). VPA has also received sharp criticism particularly by Nisbett and Wilson (1977). They conducted a series of experiments that showed that higher order cognitive processes and their reports were based on a-priori causal theories and judgments. The idea is that the correlation between what one thinks and what one says that he is thinking cannot be tested. Here a subtle distinction needs to

be made between thinking and the arising of tacit images, sounds, etc. as Ramachandran pointed out (1997). The latter are qualia laden and can be reported on, whereas the former are usually not (Ramachandran 1997), and therein lies the way forward. In the TRVP analysis used in this research this has been the main distinguishing factor between tacit experience and rationalization.

**There are three main arguments against VPA (Thatcher 1995, p39), they are:**

**The concurrent verbalization argument** suggests that the process of concurrent verbalization distorts the ongoing cognitive process, by either improving or deteriorating performance (Thatcher 1995 p 39).

**The cognitivist attack** (Thatcher 1995, p40), refers to the incompleteness of verbal reports.

This has to do with processes being unconscious, failure to attend to information as it occurs, failure to publicly report information, intentionally or otherwise, inferencing or explanations and not reporting, difficulties in identifying where a process begins, as certain processes are out of awareness.

**The epiphenomenality argument** (Thatcher 1995, p41), suggests that verbal protocols are no more than “public theories” as subjects have no access to cognitive processes. Their reporting being predetermined by a variety of factors such as cultural conditioning, rules, theories or plain association, resulting in their reporting being of no more value than the information available to the observers.

Elaborate counterarguments (Thatcher, 1995 p 41-46) taking into account the function of memory as well as other cognitive information processing evidence, together with criticisms about the methodologies used by those opposing the validity of VPA, show that VPA has merit if applied in circumstances were thinking aloud instead of explaining or rationalizing is possible. The last two were systematically avoided in this research, as the controllers’ attention was continuously brought back to describing the qualia of their tacit experience (Ramachandran 1997), which are the main distinguishing factors between rationalization and true tacit experience reports. Finally it is concluded (Thatcher

1995, p 46) that VPA can be used as a preliminary level of analysis and as a method to construct hypotheses about cognitive processes. In this research we will not be constructing hypotheses about cognitive processes, instead we will be comparing the tacit information in the controllers' minds to the HMI displays. The use of VPA in complex systems were the protocols were videotaped has been shown to hold much promise (Thatcher 1995, p 47-49). Kieras and Bovair (1984) as well as Hegarty et al (1989) employed VPA to look specifically at user's (controller's) mental representations (elicitation of mental models) (Thatcher 1995, p 49). It is stated that, "VPA data can be useful in distinguishing between those individuals who have adequate models of the system and those who do not." In further studies Bainbridge (Thatcher 1995, p 51) showed that VPA data could be arranged in the form of algorithmic flow diagrams similar to the subroutines of computer programs. This pointed to the existence of mental modeling processes in the subjects as well as qualitative decision making processes. In this research both the content as well as the sequences, tacit and explicit, of the controllers will be captured and analyzed with an emphasis on attention freedom or fixation.

The above findings extracted from VP analysis results are further corroborated in numerous examples of studies by other researchers (Thatcher 1995, p 51-59). In these reports a number of substantial benefits of using VPs are recorded, such as:

- Identification of differences between controller's mental models as compared to system designer's mental models.
- Identification of training needs.
- Identification of similarities as well as differences in controller knowledge about the system.

VP analysis was found to be accurate and therefore very useful (Thatcher 1995, p 57) and a superior tool for data gathering particularly when live video capture was used.

It is particularly interesting that under the heading "Rationale" Thatcher points out that,

> *"These operators have access to only a limited set of information, and yet have to understand the system (through the development of "complete" and accurate mental models), and act effectively in difficult and novel situations" (Thatcher 1995, p61).*

Further he states that,

> *"The designers of these (control) systems often have no real conception of the mental workload that is imposed by complex systems on the operators, they do not know what form of mental models the operators are constructing, in their training and from their work experience, or how to make the system adaptable to the cognitive diversity of different operators" (Thatcher 1995, p61).*

In Thatcher's work the VP analysis provided information about the annotation of the behavioral data and explanations for certain decisions. Only the explicit content of the verbal protocols was considered. Further analysis could take place at a later stage. No tacit information was gathered. The use of the video camera proved a very useful asset for information gathering such as the variation of how subjects perform tasks (i.e. strategies and subtask use), and where information was sought and accessed, in order to perform different tasks. The overall value of the study was that it was successful in generating hypotheses and questions for further investigation (Thatcher 1995, p 108).

It is noted by Thatcher (1995, p111, 125) that six subjects are quite adequate to provide reliable information as a previous study using VP analysis (Nielsen,1994) found that six out of twenty four subjects were sufficient to provide 77% to 85% of the useful data. It is also noted that VPs have been carried out with as little as three subjects with good results (Nielsen,1994). This is important for the current research as fourteen subjects were interviewed out of a total possible of twenty-seven.

Under general discussion it is stated that, "it is extremely difficult to establish whether the subjects are employing some sort of complete or stable mental model" (Thatcher

1995, p118), as tacit information about such models was not elicited. This is the area where this research will be making a contribution. It is also stated that due to the great variation in the results it seems that the subjects hold dynamic rather than fixed mental models which are updated from moment to moment. Thus from a common starting point they can develop rapidly diverging perspectives on the state of the complex system. However no information is provided about what these may be. Other researchers have also concluded that operators' mental models are incomplete, inconsistent, and unstable with detrimental consequences of poor visual momentum and cognitive tunnel vision (Thatcher 1995, p 109-119). Some of these elements will be investigated in this research. However, in Thatcher's study mental models are not described explicitly and as such the tacit domain remains invisible. It is at this point therefore that the current research takes over in order to identify what the visual and other representations in the controllers' minds are as they work with their mental models on the network simulator.

### 2.10.3 Retrospective Verbal Protocols

Ericson and Simon (1993) are two of the main contributors to the VP field as they identify areas where tacit processes and content are to be considered. However like the work reviewed above there is no mention of actual data, or examples, given of the tacit domain, its content, and structure. Under the section on "Verbal Reports of Cognitive States and Structures", reports on short and long term memory experiences are mentioned and discussed, under the term "Retrospective Verbal Protocols" (RVP). However, the tacit aspect of memories, or descriptions and the associated qualia are left unattended as far as the actual structure and tacit content of such memories go. One comment from Cannell et al., (1981), states,

> *"When subjects give quick responses, they should be encouraged to think and retrieve more, … the interviewer should try to get the subject to make an explicit agreement to respond accurately and completely." (Ericson & Simon 1993, p 37).*

This is a good indication that the interviewer should encourage the person interviewed to report on deeper tacit phenomena during a RVP, but there is no further elucidation in the text. In the section on the history of such introspection (Ericson & Simon 1993, p49), William James is cited as the pioneer in this field, making use of natural unself-conscious introspection. Other pioneers, like Titchener and Wundt (Thatcher 1995, p50), held the hypothesis that all mental states and experiences could be described in terms of their sensory and imaginal components (Ericson and Simon 1993, p51). According to Wundt, human experiencing of external events has two phases. First, the sensory attributes of the external event are experienced. Then, other interpretive processes occur, which relate the sensory input to existing knowledge and prior experiences. It is therefore the second phase that makes up the cognitive phenomena we call consciousness. In the current research it is the second phase phenomena, which arise spontaneously, that are of interest as they precede the overt interpretive phase (Ericson and Simon 1993). Differences in the way we experience the same sensory stimulation are due to variations in the associations evoked by the external experiences (as a result of the second stage). All experience corresponds to a conglomerate of sensations, therefore the structure of the mind and consciousness, can be described in terms of sensory components. It is further stated,

> *"Titchener's proposal was that consciousness should be described in terms of its elementary components. The introspective reports requested by Titchener were very different from the phenomenal accounts provided by naïve introspection. Subjects required extensive practice to break away from their habits of giving phenomenal accounts" (Ericson and Simon 1993, p 51).*

This was guarded against in the current research too, as subjects were directed to giving descriptions of what happened in their mind in great detail by focusing on qualia descriptions (Ramachandran 1997). The initial tendency to commit what he calls the "stimulus error" was discouraged, which was to report information reflecting previous experience and knowledge from the second stage (for example, to report "seeing a book"), instead of reporting the sensory and imaginal components such as it size, shape, location, etc. (Bandler & MacDonald 1988). A ten-second period of thinking sometimes required as many minutes to recount and make clear (Woodworth, 1938, p. 783). These

accounts address the tacit domain and appear to speak directly to the methods employed in the present research.

Sperling (1960) (Simon & Ericson 1993, p56) found that the duration of these “iconic” descriptions of sensory stimuli were shown to exceed the capacity of Short Term Memory (STM), even when their content endured only a fraction of a second. It is further stated that introspective reports are subject to several sorts of selective bias including the theoretically based training of observers, the uncontrolled use of questions (Humphrey, 1951), and the fact that subjects (often faculty and students) are often aware of the aim of these studies (Comstock, 1921). It is shown that VP and RVP reports provide a nearly complete record of the sequence of information that is heeded during task performance. The issues of epiphenomenality and idiosyncrasy of verbal reports are also discussed, and it is demonstrated that verbally reported information is as regular and valid as other types of data (Ericson & simon 1993, p220). Then the detailed models of processes, which take place during verbalization under think-aloud and talk-aloud conditions, are presented. This is followed by the theoretical model of verbalization in order to examine and evaluate coding schemes and procedures, together with the description of methods of analysis that are reliable and valid, (Ericson & Simon 1993, p221). Then a number of detailed examples are presented of some ways in which protocol analysis can be carried out within the framework of information processing. Finally in the last chapter, transcribed verbal protocols are presented. From these the tacit domain can be clearly inferred but not directly discussed. A concluding remark (Ericson & Simon 1993, p373) states, “ There was a time when introspection was the only way forward in psychology, then behaviorists rejected verbal reports as data. It is now time for verbal reports to reassume their position as a rich source of data, combinable with other data that can be of the greatest value in providing an integrated and full account of cognitive processes and structures”. A limitation of this work is that in most cases the subjects used in the studies cited in the book are not experts in the field, i.e. they do not have inherent images and sequences of operations, which emerge spontaneously in response to computer display or other external stimulus/information. This is something that should be carefully taken into account when reporting on issues of expertise. The content of the protocols presented

consists of statements like, “I did that, or thought this etc.” In these there is no account given about the qualities of the qualia, and structure of the images themselves as seen or talked about. For the purposes of the current research this is very important, and it is in this respect that the present findings can make a contribution to the body of knowledge.

In all the papers and books reviewed above there is no explicit mention of the visual, auditory, or kinesthetic representations (qualia) of the mental experience of individual subjects doing a particular job, under particular conditions. In most cases where mental models are mentioned it seems obvious that such visual representations are present and could be accommodated. However, no mention is made explicitly. Ericson and Simon (1993) discuss the presence of the tacit level of mental processing, however like Thatcher (1995), they omit any actual information or procedures to elicit such tacit phenomena or actual information about what these tacit representation look, sound, or feel like. It is important to draw the distinction between Thatcher and Ericson’s emphasis on problem solving strategy investigation and the emphasis of this research. In this work, the main emphasis is the identification of the tacit representations in the minds of the controllers of what has been referred to as “their mental models” which underpin the above strategies and problem solving efforts. **Also another very important factor is the fact that subconscious representations can be elicited as distinct from rationalizations and ordinary thinking because they are qualia rich (Ramachandran 1997) while the latter are qualia poor. This is the key to getting to the subconscious or tacit level.**

### 2.10.4 Tacit Retrospective Verbal Protocol Analysis (TRVP)

Of the various elicitation methods mentioned, which could be used to elicit the tacit representations, a modified version of Retrospective Verbal Protocol analysis (RVP), the Tacit Retrospective Verbal Protocol (TRVP) was used in this research. This new analysis methodology was created by including the use of the Metamodel questioning approach and sub-modality (or qualia) elicitation (discussed below) of Bandler and Grinder (1975, 1977, 1980, 1988, 1992, Dilts 1998, O’Connor 2002, Bodenhamer & Hall 2002). This

was done in order to expand and uncover the underlying mental complex equivalences that the controllers use to give meaning to their tasks. In this way the RVP methodology was extended to include the subjects' descriptions (not explanations or reasoning which are qualia poor, Ramachandran 1997) of various aspects of their mental experience (visual, auditory, and kinesthetic in particular) thus creating the TRVP. This was done by eliciting the components or qualia of the controllers' spontaneously arising mental tacit experience, and their combinations, as they arose in response to what was displayed in front of them on the screens. In other words the controllers were able to describe what the actual images of their mental models looked like, if they were in color, what was their size, how complex they were, and how those images resembled or differed from the images on the computer monitors. Also elicited, was what their thoughts sounded like, what their inner voice(s) were saying, and how the whole experience felt in the simulator, and how that compared to what they felt inside the control room itself. In order to achieve this the techniques discussed below were used.

## 2.11 Review of the Neuro-Linguistic Programming (NLP) Field.

In this review the various aspects of the NLP human expertise modelling process were identified and are summarized. The NLP field consists of various methods and techniques, which can be used to elicit information and effect behavioural changes in subjects. **There is not much theoretical content in the NLP field; in the section below a summary of the relevant techniques is presented.** The pioneers of NLP, like Grinder and Bandler, have developed these techniques by observing the behaviours of experts like Virginia Satir, Fritz Perls, Milton Ericson, Gregory Bateson and others. However in NLP terms, the word "unconscious" is used to mean anything that is not in present moment awareness.

> *"The unconscious mind is made up of all those mental processes that continue without our knowledge. The phrase "unconscious mind" is a nominalisation. The unconscious is not a thing but a process. It deals with the deep life-sustaining functions and the thought processes that break through into the conscious mind, like bubbles bursting on the surface of a pool. The*

*conscious mind is what we are aware of, but, like the sea, it has hidden depths that support it" (O'Connor 2001, p169).*

In this respect, of particular significance is the "Metamodel" process (Grinder & Bandler, 1975), which was used to reveal the hidden layers of meaning structured in the "unconscious" of the interviewed controllers' minds. The sub-modality elicitation (Bandler & Macdonald 1988) section is also very significant as it provides the framework used to reveal the tacit content of the controllers' mental representations (or qualia, like colour, black and white imagery, etc.). The RVP techniques mentioned above provide the platform and the means together with the material covered below with which to reveal the tacit domain through interviews. Thus, adding what is referred to as NLP modelling, to the RVP has led to the creation of the TRVP. This researcher has had many years of training in NLP (is a registered NLP trainer with the Southern Institute of NLP USA) and has applied it in diverse fields (engineering, education, business etc.). This is mentioned because it takes considerable training for a person to be skilled enough to apply these elicitation techniques properly.

### 2.11.1 The Modelling Process

As identified from the various references cited (Dilts 1998 (chapters 1-4, 6), Dilts, Grinder, Bandler, & De Lozier 1980, (chapters 1-3), Bodenhamer & Hall 2002, (vol. I chapter 15, vol. II chapters 15 & 16)), the stages of modelling human expertise can be summarized as follows:

- Elicit the relevant data, and gather information from expert/s.
- Formalise the information and structure the model of expertise.
- Transfer the model to non-experts.

It is important to keep in mind the stages of learning in order to appreciate that the experts being modelled, may very well not be fully aware of the tacit structure of what they do so well.

The stages of learning (O'Connor, 2002) are:

- Unconscious incompetence (state of ignorance of ignorance);
- Conscious incompetence (beginning of learning);
- Conscious competence (practicing what has been learned);
- Unconscious competence (expert performance);
- Conscious/Unconscious competence (ability to interact with own tacit elements of expertise).

These stages are similar to Anderson's stages (Anderson 2002, p 273) of competence acquisition, which were mentioned earlier. If the person modelled is an expert, they will most likely be in the second last category. It will be the task of the researcher to move them into the last category by asking Metamodel and sub-modality elicitation questions. This is necessary, in order to elicit and record the various aspects of their internal representations and their underpinning structure. Some of the identified aspects of the expert's performance may remain out of their conscious awareness even after the elicitation process. This process unfolds in layers, and it is necessary to know when to stop once what is required has been obtained.

During the elicitation process it is necessary to:

- Listen to the words that the subject uses;
- Observe the subject's behaviour; and
- Identify the underlying intentions of the subject.

In preparation for elicitation it is necessary to consider the following:

- Is behaviour being modelled , internal representations or both?
- Review the presuppositions that have been identified during the preliminary interviews.

- What methods of elicitation will be used?
- One on one interview.
- Observation of performance of the task, with or without commentary.
- Video recording.
- Audio recording.
- Group elicitation.
- Mixed.

All but the last two methods above were used in the interview process, in this study.

Then it is also important to consider if the level of detail of the information elicited is appropriate to the outcome required in the research. To determine this, the prevailing external and internal factors as well as any constraints should be considered. Then it is important to determine how will the data be formalised, by what means and on what level of detail. Finally it should be decided how would the models elicited be transferred to other controllers, after they have been formalised/simplified. Will this be done in the form of:

- Live presentation;
- Manuals;
- Audio visual;
- Interactive media;
- Expert systems/simulation training;
- On paper; or
- Mixed.

The presentation of the models elicited, to other individuals within the NCC environment, does not form part of this work. Aspects of the models themselves however will be presented in this thesis in written form.

In preparation for elicitation, the interviewer must note the following requirements:

- Be clear about what is to be elicited, yet flexible enough to allow other important issues to come through.
- Ensure that all your sensory channels can be used.
- Establish a way to maintain focus on the other person and not drift into own thoughts.
- Establish ways to maintain energy levels during the interview process.
- Establish ways to either associate or disassociate from the subject.
- Ensure that the individual who is being interviewed is met at their model of the world.
- Be familiar with the jargon of the field in which the person that is being interviewed works.
- Establish rapport with the controller first, before the elicitation process begins.

During the interview process it is possible to go from:

**Macro aspects:**

- Values (emotionally significant elements)
- Beliefs (thought that the person holds as true)
- Linguistic metaphors
- Sorting styles (preferences used for selecting aspects of information)

**To Micro aspects:**

- Strategies (Sequences of internal and external processing)
- Modalities (Five senses)
- Sub-modalities (Qualia, or elements of mental sensory experience i.e. images in colour or black and white, the direction from which inner voices come from, etc.)

In each case it is necessary to pay attention to the internal and external, conscious and unconscious, overt and tacit aspects of the subject's experience by noticing what

information is being conveyed by hand movements, eye movements, and any other postural elements, voice fluctuations, pauses, etc.

Choose the format (mind map, lists, video, etc.) and the material that will be used (note pad, flip chart etc.) to log the various dimensions of the subject's experience.

### 2.11.2 **Logical Levels** of mental processing

The terms below refer to what as known in NLP as "logical levels" of organization of experience, or mental processing, or "neurological levels" [O'Connor, 2002]. This view is also presented in Pinker's (1999), Anderson's (2002), and Shalif's (1987) work. They however do not use the term logical levels, instead they speak of the way the brain is structured in expert "modules" that interact with each other in neurological hierarchies of organization. The purpose of listing them here is to present a framework, which can be used to probe the deeper layers of the information, presented by the controllers. The idea is that behaviours are possible because of abilities; they are in turn activated by beliefs and motivated by values or the desire to experience certain states of being (Pinker 1999, Anderson 2002, Shalif 1987). These states as a collective define an individual's identity and that identity (Pinker 1999) is then considered as part of a greater context or whole. In this case it would be the NCC and the controllers' lives at large. The relevant aspects of these "levels" that are experienced in terms of the qualia, which constitute them, will be elicited in this research. This is by no means a linear process as the brain is a parallel processing entity with many multi-connected layers (conscious and subconscious) operating at once (Pinker 1999, Anderson 2002).

Starting from the top (higher complexity), these levels are:

**Beyond Identity** — This level represents a controller's "connection" with structures beyond his/her sense of individual self (i.e. family, working group, society, etc.).

**Identity** This refers to the controllers' sense of identity within the control room environment. Controllers have indicated in the past that they have particular "professional" identities, which get activated in the control room environment (Lazanas 2007).

**Values** The value of something is defined as the "state" that it creates within an individual. Shalif (1987, 2004) states that we are motivated by our need to achieve emotional states rather than the results of our actions. We use whatever skills we have to achieve results so that we can experience the emotional states they create. In other words it is the state, behind what we achieve, that we really want. "How will you feel when you have what you want" or "what do you value the most in this situation" are typical questions asked in order to elicit values.

**Beliefs** Beliefs are thoughts, which the controllers hold to be true. What was elicited were the beliefs which the controllers hold about the network, themselves, their ability to control it, and how their work environment will effect them in the long run. "Why" is the preferred question to elicit beliefs. Means of access to beliefs are:

Curiosity
Comfort
Security
Affiliation
Knowledge
General / Specific
Other

**Abilities** The underlying abilities, behind the controllers' behaviours, were identified from what they did on video. These are activated by the controllers' beliefs and represent the "how" of doing things.

**Behaviours** These were the demonstrated behaviours off the video footage. They are the "what" of that which was observed.

**Environment** This represents the "where and when" of the observations, or the simulator room in the NCC working environment.

### 2.11.3 Sorting Styles (or filters)

In order to manage the enormous variety and volume of information coming from the world "outside", as well as the world "inside", we make use of filters or "sorting for" mechanisms. Each individual has their own unique set of such filters and in this way develops a "sorting style" like the ones given below as examples.

**Sorting Styles** These are the filters through which information passes ("sort through" means to filter), in order for controllers to determine what is relevant to them. Below is a list of things controllers may be focussing on in their work. The list is given in no particular order.

| | | | |
|---|---|---|---|
| Information | Past | Associate | Centeredness |
| Others | Present | Dissociate | Timelessness |
| People | Future | Places | Positive |
| Activities | Match | Shift | Negative |
| Things | Mismatch | Relationships | Feelings |
| Approach | Interior | Power | Other … |
| Avoidance | Exterior | Inspiration | |

### 2.11.4 Metaphors

Further, metaphors are a convenient and effective way to integrate the complexity of our mental representations of the world and presented them to others. By the use of

metaphors we can incorporate the technique of “this is like…” in order to use qualities and complex correlations implicit in the metaphor and “map them over” to the idea or topic at hand. For instance to say that a man is like a “bear” implies a lot of complex ideas associated with the word “bear” that go much further than saying that he is “big”. This type of description is distinctly different from ordinary technical language, in that it seems to be infused with emotions that make the metaphors appear real and tangible to the narrator. This signals the shift to deeper layers of meaning. To facilitate the transition to these deeper layers the Metamodel set of questioning techniques, as proposed by Grinder and Bandler (1975), were used. These questions revealed the complex equivalences of words by facilitating searches within a person’s unconscious.

### 2.11.5 Metamodel

The Metamodel technique (Bandler & Grinder 1975) represents a method of identifying and overcoming the linguistic violations listed below. It was created by Grinder and Bandler modelling Virginia Satir’s and Fritz Perls’ questioning techniques (Bodenhamer & Hall 2000). It involves asking specific questions in such a way as to reveal the hidden, deeper level, meaning of the words that the controllers used. In NLP terms it represents moving from the “surface structure” of normal linguistic expression to the “deep structure” of subconscious mental representations. By using this technique during the interviews the controllers’ inner tacit representations were identified. The list of terms below is defined in the literature (Bodenhamer & Hall 2000).

**Deletion:** (Important information that is left out.)

Simple/Comparative (Like “I am afraid…” of what? Or “He is better…” than whom?)
Deletion:

Unspecified Verb: (Like “He hurt me…” how?)

Unspecified (Words like “they…” who are “they”?)

referential index:

| | |
|---|---|
| Judgments | (Like “This is better…” than what?) |
| Comparisons | (Like “He is the best…” Compared to whom? |

**Generalization:** (One example of a class is taken to represent the class.)

| | |
|---|---|
| Modal operators of necessity: | (Things “must” be so) |
| Modal operators of possibility: | (Like “ I can’t visualize…” |
| Universals: | (like “ All the time” or “you always …” |
| Lost Performative | (Like in “boys don’t cry” which “boys” are we referring to?) |

**Distortions:** (Information that is distorted)

| | |
|---|---|
| Nominalizations: | (Represent processes as if they are nouns, like the word “relationship” is a process and not a noun) |
| Mind reading: | (Assuming what others think about something) |
| Cause and effect assumptions: | (Presuming cause and effect relationships which may not exist) |
| Complex equivalences: | (“This” automatically means “that”) |

Presuppositions: (Assumptions about how things are like, "work harder" assumes that the person concerned is not working hard enough)

The table below is a list of the linguistic violations, which can be interrogated by using the Metamodel, the Metamodel questions which will counteract them, and the result/benefit obtained.

Table 2.11.5.A. Metamodel violations, questions, and benefits (Bodenhamer & Hall 2000, p157).

| **Pattern** | **Response/Question** | **Prediction/Result** |
|---|---|---|
| **DISTORTIONS** | | |
| 1. Nominalizations<br>Process words frozen in time e.g. "We lack communication" | Turn noun back into verb<br>"Who's not communicating?<br>Or "How would you like to communicate?" | Recovers the process, actions, movements, etc. |
| 2. Mind Reading<br>Claiming to know someone's internal state e.g. "You have a problem with authority" | Question source of data<br>"How do you know…?<br>"What lets you know…? | Recovers source, means, discovers process. |
| 3. Cause-Effect<br>"Causation" assumed without adequate description e.g. "You make me angry" | Ask about process<br>"How does what I do make you choose to feel angry?" | Recover the mechanism that explains the cause |
| 4. Complex Equivalence<br>Two experiences interpreted as synonymous e.g. "Her frown means she's rejecting me" | Ask about the equation<br>External behaviour = Internal state "How do you equate the frown to rejection" | Recovers the External behaviour and internal state |
| 5. Presuppositions e.g.<br>"If you knew the importance of school, you would study harder" | Ask about assumptions<br>"What leads you to think I don't know the importance of school?" or " I don't study hard enough?" | Recover assumed ideas |
| **GENERALISATIONS** | | |
| 6. Universal Quantifiers (generalisations) such as, all, every, never, no one, etc. | Find Counter Example<br>"All?"<br>"Never?" | Recovers exceptions, causes, details, Counter Examples |
| 7. Modal Operators of necessity/desire as is should, shouldn't, must, must not, have to, it necessary, etc. | "What would happen if you did?"<br>"What would happen if you didn't?" | Recovers mode of operation and causes |

| | | |
|---|---|---|
| 8. Modal operators of possibility/impossibility, like can't, may/may not, etc. | "What prevents you?"<br>"What would happen if you did?" | Recovers mode of operation and causes |
| 9. Lost performative<br>Value judgements apart from originator e.g. "It's bad to judge" | Seek source of statement<br>"Who says it is?"<br>"How do you know?" | Gathers evidence<br>Recovers source |
| **DELETIONS** | | |
| 10. Simple deletion e.g.<br>"I am uncomfortable" | "About what/whom?" | Recovers deletion |
| 11. Comparative deletion<br>As in good, better, best, worst, more, less, most, least, e.g. "She's a better person" | "Better than whom?"<br>"Better at what?"<br>"Compared to whom? | Recovers comparison source of reference |
| 12. Lack of referential index.<br>Unspecified nouns and verbs, fails to specify person or thing, e.g.<br>"They don't listen to me" | "Who doesn't listen to you?" | Recovers the noun or referential index |
| 13. Unspecified Verbs<br>Those verbs where the statement leaves out the person doing the acting or the desired action.<br>"You don't care about me." | "How specifically do I not care about you?" | Specifies the verb |
| | | |

By using all of the above techniques, the controllers' attention was moved from the surface structure of everyday thinking to the deep structure underlying it, where the tacit experiences to be elicited are located. Once that was achieved the actual content and structure of that subconscious domain was further explored by means of the sub-modality elicitation technique below.

### 2.11.6 Sub-modalities

The other very important aspect of the interview process is the modality and sub-modality elicitation (Bandler & Macdonald, 1988). What was pointed out in the Metamodel section above was that there are many layers of meaning in the spoken word. What is considered now is the structure of meaning itself, as rooted/structured in terms of experiential components (qualia), the elements of the mental sensory information (Ramachandran 1997; Pinker 1999; Anderson 2002). The idea is, that before a word can

be experienced it has to be represented sensorialy; this could be the auditory aspect of the word in our mind or the mental visual depiction of it, etc.

We normally think of five primary senses, visual, auditory, kinaesthetic, olfactory and gustatory, these are termed modalities. For the purpose of this research the visual, auditory and kinaesthetic senses were only considered, as these are the ones considered the most relevant in the NCC environment, given the research question. In this section the sensory structure of the words used by the controllers is described. In other words, if a controller mentioned the word “grid” it was required of him/her to describe in what way exactly did he experience the “grid”. Did he see it as an image, hear it as a sound, feel it as a feeling, or a combination of these?

**Modalities** are the five senses through which we process all information, as well as represent it to others through the medium of words. The words that the controllers used indicated which modalities they were experiencing, which was their favourite etc. It was expected that some controllers would have difficulty in changing from the kinaesthetic to the visual modality because of the way that they spoke in the preliminary discussions. Shifts in modalities were noted as the person went further into their description of their tacit experience. The sub-modality aspect (defined below) of the sensory structure of experience was the last layer that was elicited. An individual’s expertise is structured in terms of experiential components that operate very much like computer software. For instance, using the example of the word “grid”; if the experience of the word “grid” was visual it was determined whether the image was in colour or black and white, how far from the viewer it appeared mentally (its sub-modalities) etc. In this way the controllers’ mental worlds were explored (Bodenhamer & Hall 2000, O’Connor 2002).

**Sub Modalities** represent the constituent structural components of the sensory
Modalities mentioned above (Bodenhamer & Hall 2000, O’Connor 2002). Here are some examples:

**Visual:**

Bright / Dim; 3D / Flat; Distant / Close; Movie / Still; Associated / Disassociated; Black-White / Colour; Type of colour; Orientation; etc.

**Auditory:**

Tone; Tempo; Constant / Intermittent; Voice (male / female); Emotion conveyed by voice; Direction of sound; etc.

**Kinaesthetic:**

Location of sensation; Size; Movement; Pressure; Texture; etc.

For each modality the sub modality structure of each individual's experience was explored. In order to do this it was important to allow lots of time for the controllers to access the richness of their tacit experience. Having sought permission, layer after layer of the structural components of the mental representations used by the controllers was uncovered.

In the next section the sequence aspect, of the structure of experience or expertise was identified (Grinder and Bandler 1975). The word strategy can be used to refer to the sequence of actions and mental processes that a controller may use, as well as the order in which the mental experiences themselves are structured at their modality and sub-modality level.

For instance, a controller may "see" a mental image of the whole of the ESKOM grid then mentally "zoom into" a particular section, then do something on the HMI, etc.

### 2.11.7 Strategies

Strategies are the *sequences* of Visual, Auditory, Kinaesthetic, Olfactory, and Gustatory experience. The Test, Operate, Test, Exit (TOTE) (Dilts et al. 1980) model is similar to the one presented by Pinker (1999):

- The elements, which comprise an object, are identified from those around it.

- The object is recognized.
- It is then mentally manipulated.
- It is given meaning through association and it's emotional significance identified.
- A sequence of actions is tacitly or consciously identified such as to achieve a desired objective with respect to it.
- The actions are performed and the result compared with the desired outcome.
- The process is repeated if required.

The sequencing of a controller's internal and explicit processing can be identified and used in the design of suitable computer interfaces, train others, etc.
These sequences are mapped out by using symbols like $V_e$ to indicate looking out (Visual external), or $V_i$ looking within (Visual internal), etc., similarly for the auditory and kinaesthetic modalities. The sequences are then analysed to identify best practice strategy structures, where for instance a particular controller who may have the ability to do something well can be used as a model to train others in the sequence of "attentional" operations performed to achieve a result.

### 2.11.8 Body Language

As much as 93% of the meaning of verbal communication lies in intonation and body posture (O'Connor, Seymour 1993). As a result, special care must be taken to notice subtle unconscious movements for clues to the underlying states implied by the words used by the controllers. Often, what is being conveyed by a person's physiology (their hands in particular) is truer than what is being revealed through their words. What has to be considered is a state of congruence between what was being said and the speaker's physiology. Incongruities should be explored as far as possible. If a person would say, "I don't know about the connection between these two stations" while moving his hand up and down this may indicate the presence of some "line" in that implied mental location. Therefore more questions about its appearance, colour, etc. would have to be asked.
The following were considered:

**Mannerisms** (patterns), as well as anything that stood out by overdoing or not doing.
Use of the left or right side of the body, hand and finger movements, head tilt and eye movements and what they stood for (visual, auditory, kinaesthetic, positive / negative, past, present, future), feet, mouth, hidden vs. exposed parts, conscious vs. unconscious movements, direction (facing, opposite, with, etc.).
The method of mirroring the physiology can be used to verify the feelings that are being talked about thus confirming congruence.

Examples of the physiological aspects that were considered are, in no particular order:

| | | |
|---|---|---|
| Physiology | Location of tension | Eye Blink |
| Breathing | Muscles | Head Nods |
| Gestures | Posture | Head Location |
| Mouth movement | Hand movements | |

### 2.11.9 Emotions

In NLP terms, emotions are very important aspects of experience. As mentioned above they are considered under the broad “kinaesthetic” modality and sub-modalities. The work of Shalif (2004), and in particular the emotion bipoles was added to the material used for this section. The controllers’ descriptions of “emotional energy”, flow, authority, power, love, coercion, etc., among the control room staff were also noted.

### 2.11.10 Other Elements

The ability to have “perspective” on a situation depends on how a person is mentally “positioned” with respect to the situation at hand. In general, when a person is fully associated with an experience they are able to feel and act; when they are dissociated they are more able to evaluate and make comparisons. Further, the ability to empathize with others, to see / feel things from the other’s point of view, is also an important ability

when it comes to teamwork. In the NLP context these skills are referred to as perceptual positions they are:

- **First** (Describing events through their own eyes).
- **Second** (Describing events through the eyes of another person).
- **Third** (Describing events from a distance, looking on themselves in the events described).

The perception of time is subjective, both with respect to "real" time as well as whether a person is focused on the past, present or the future. The flexibility to be able to focus on any one of these time domains, at will, is part of what makes an expert controller. This is because they have to remember past events, clearly sort out current information, and anticipate events and the consequences of their decisions. As a result, the way time was perceived, which time domain the controllers focused on, and in what order was investigated. The time orientation of the controllers was noted as past, present, or future. Hand locators or other expressions and gestures for past, present, and future were noted.

Any other evidence that was provided was collected and added to the overall set of material that was used to make explicit the controllers' inner worlds. Such evidence included:
Written material; drawings; doodles; environmental factors; demonstrations; representations; buzz words; jargon; symbols; tools; software / hardware; photographs; traditions; rituals; rules; technical knowledge; theories, etc.

All of the above techniques have been applied in a variety of contexts as discussed in the NLP literature (Dilts 1998).

## 2.12 The Tacit Retrospective Verbal Protocol (TRVP)

All the NLP modelling techniques, mentioned in the section above, were used during the interview process. However the metamodel and sub-modality elicitation techniques were

the most useful in eliciting the tacit content which is at the core of this research. By using metamodel questioning techniques it was possible to bypass the generalisations, distortions, and deletions used in normal conscious expressions, by the controllers, regarding the events that took place in the simulator exercises. In this way it was possible to move from “surface structure” to “deep structure” descriptions of the experiences in controllers’ minds. This process was further refined and focussed by using sub-modality elicitation techniques. In this way the retrospective description of the events in the controllers’ minds was made possible. This new approach where traditional RVPs are combined with NLP metamodel and sub-modality elicitation techniques is termed Tacit Retrospective Verbal Protocol (TRVP).

## 2.13 Conclusion of the Literature Review

From all the above reviewed areas it can be concluded that controllers who work with HMI displays obtain information from them in varying time frames. This information often demands quick decisions to be made in time frames such that time consuming analytical thinking cannot be applied. In such short time frames subconscious decision making processes dominate. It is well accepted that these subconscious processes and content drive behaviour under such circumstances. Combining aspects of NLP modelling techniques with traditional RVPs can reveal these tacit processes and content. This leads to the creation of the TRVP methodology. In this way tacit or subconscious aspects of controller expertise can be revealed and analysed.

## 2.14 The Research Question

Having established that the presence of tacit content and structure are the main drivers of behaviour under short time frames is well accepted in the field of psychology, all the above can then be simplified into a brief research question stated below:

**What are the tacit mental structures, content, and emotions, which arise within the minds of the controllers at the NCC, as they work with the newly implemented Windows based TEMSE computer interface?**

This is the question, which will be addressed in the following chapter in terms of the detail of the methods that will be used to provide an answer to it.

# Chapter 3:

# METHODS

Having concluded the literature review, what will be presented here is the sequence of events as they unfolded, in order to conduct this research. After the sequence of events, the methods used at each step for verifying the hypothesis by means of the simulator exercise and the interviews will be presented, as well as what was considered in the analysis of the results. In this way the methods and sequence of the research are fully laid out for any one to replicate in any other similar environment. It is also understood that in order to conduct this type of research suitable training in the techniques mentioned is a must.

## 3.1 Chapter Content

In this chapter are included:

1. An introduction.
2. The steps taken to conduct the research, in point form.
3. The participants' list.
4. The description of the network simulator exercise in detail.
5. The detail of what was elicited during the interviews, the reasons for doing so and the methods used for each area of the research.
6. The methods of analysis used to interrogate the data for each stage of the research.
7. The equipment used.
8. Ethical considerations.

## 3.2 Introduction

In this chapter the various elements from the previous chapter will be combined to create the research methodology to be used in this investigation. In other words, keeping in mind the research hypothesis, the Tacit Retrospective Verbal Protocol (TRVP) methodology will be used to elicit a variety of information from the controllers at NCC, as listed in the sections below. It is the use of this new technique (TRVP), which sets this research apart from what has been done before.

## 3.3 The Steps Taken to Conduct the Research.

This section outlines the steps taken in order to answer the research question. The details of the methods used in the research for each of the steps below and the analysis criteria will follow in the next section.

The following steps were taken to arrive at the final result:

1. Preliminary discussions were conducted with the NCC (National Control Centre) management to determine their needs. These initial interviews were simple and informal.

**Outcome:** List of needs and finalization of research theme and invitation to do the research.

2. Preliminary discussions were held with the training manager and other staff at the NCC.

    a. The training staff were informed about the aims of the research and scheduling began in order to allocate times on the simulator for the various participants who had volunteered for the research. This presented quite a

challenge as during 2010 South Africa hosted the FIFA World Cup, which placed extraordinary burdens on the NCC staff.

b. During previous encounters, over a number of years, it became possible to hear firsthand what the controllers feel about working with the two types of computer displays (the old one ENCOR, and the new Windows based one TEMSE) and the problems they encountered. Discussions were held in the control and training room environments during day and night shift work. The time spent in the NCC prior to conducting the research was of paramount importance. This was done in order to appreciate the actual working conditions and thus put the simulator work that followed, in the right perspective.

c. From all the above, a list was drawn up with a variety of needs, those that pertained to the research questions and those that did not. The latter category will not be included here, however it was used to inform the research context and to reveal other issues that may have a bearing on it.

d. The contingencies to be presented to the controllers on the simulator were discussed with the NCC training manager and his staff and the relevant case files were drawn up ready for the simulations.

e. The NCC training manager drew up the list of controllers who were willing to participate in the research. He personally elicited their support without any conditions. All the controllers, included in the list of fourteen, were volunteers. The list was drawn up such that all of the following characteristics of the staff in the NCC were represented:

- Job title (all job descriptions in the NCC),
- Race group (Black, White, Indian, Coloured),
- Years of experience / service (1, 3-5, 5-10, 10+, years in the NCC)
- Gender (Male, Female)
- Age (20s, 30s, 40s, 50s)
- Qualifications (all the qualifications within the NCC),

- Controllers who have no TEMSE experience (had been out of the control room for the years that TEMSE was introduced)
- Controllers who have no ENCOR experience (not at NCC when ENCOR was in place).

**Outcome:** The list of the fourteen volunteer controllers was compiled and the content and the steps to be followed during the simulator exercises and interviews were designed.

3. The information about the project was conveyed back to all stakeholders so that everyone knew what the project was about. The controllers were not told what to expect in the simulator except that they would be faced with some contingency conditions and that they had to do their best to maintain system integrity, particularly voltage stability. Nielsen (1994) showed that as few as six participants were sufficient to elicit 77% to 85% of the relevant information for a VP type investigation. In this case half of the staff at the NCC (50% or fourteen controllers) were used and in the participant group every relevant variant was included as mentioned above.

**Outcome:** Confirmation of the participation in the project of the volunteer controllers on the participants list by the NCC training manager.

4. A literature review was conducted to establish the relevant background information for this research as well as to provide the background to the research questions, as follows:

    - What are the time frames in which controllers' have to respond to network phenomena? These in turn determine the mental processes (tacit or conscious) available for doing so.
    - What are possible HMI formats and graphic representations available in the Power System Visualisation field?

- What are some of the currently valid theories of cognition and tacit mental processing?
- What elicitation techniques would be relevant for this research form the Engineering Psychology field?
- What alternative elicitation methods are available from the NLP field?

The literature review included the fields of Electrical Power Network Visualization, Cognitive Psychology, Industrial/ Engineering Psychology, and Neuro-Linguistic Programming (NLP) as mentioned in the literature review.

**Outcome:** A list of papers, books, and any other materials identified in the course of the investigation was compiled, and then discussed with respect to the research question. The shortcomings of the various sections were identified and the means to address them was set out.

5. From all the above, the structure and process of the interviews (this is discussed further down) was formulated.

**Outcome:** The interview methodology was designed in an appropriate format.

6. Using the above methodology in step (5), a series of interviews was conducted, over a year on an individual basis. During these interviews the tacit aspects of the controllers mental processing relating to the TEMSE Windows based computer displays were elicited using the TRVP method. These interviews were video recorded.

   The research process included the following steps:

   a. During the first part, each controller was given a task to perform, which consisted of attempting to maintain the integrity (with respect to voltage stability) of a chosen region of the Eskom network on the NCC network

simulator. This step of the process was video recorded for further use and analysis. See a more detailed description in the relevant section below.

b. During the second part, participants were first asked to briefly write down what happened during their simulator work.

c. Then a short section of the recording of their activities from the previous step was played back to them in order to initiate the structured interview investigation into their tacit representations.

d. Then the interview process itself began (see the relevant section below for details), using the TRVP with "Metamodel" and sub-modality elicitation techniques added to the standard RVP method in the literature review section. These techniques are fully described further on in this section. The controllers' descriptions of the tacit visual, auditory, and kinaesthetic, mental representations while working with the new TEMSE Windows based displays were elicited and video recorded. During this step questions were asked about whether the mental images in their mind resembled the ENCOR or the TEMSE type displays. The process also included questions about other aspects of their work in the control room as listed below as well as a questionnaire to elicit their emotional responses during their work in the control room.

**Outcome:** Video recordings of the interviews in unprocessed format, diagrams of mental images, and emotion questionnaires were obtained from each controller.

7. The video recordings were analysed and the relevant information was extracted, ordered, and summarised. The criteria for the analysis and how it was done are described later on in the section dealing with Analysis below.

**Outcome:** Results and summarisation of findings in the different categories addressed in the research.

8. Conclusions and recommendations were formulated and suggestions for further research identified.

**Outcome:** Conclusions, Recommendations, and further research possibilities.

9. Final written Thesis.

**Outcome:** Documentation as per faculty requirements.

## 3.4 The List of Participants

Fourteen controllers participated in the research project. They were all volunteers. This is just over 50% of the total of twenty-seven staff doing shift work at the NCC in 2010 (this number is not fixed as new trainee controllers come into the control room at different times of the year). Nielsen (1994) found that six out of twenty four subjects (25%) were sufficient to provide 77% to 85% of useful data. Normally there are twenty-five full time controllers (five shifts with five members per shift) working at the NCC.

In this section we look at the job description, race, the years of work experience, gender, age, qualifications, ENCOR and TEMSE work experience, as shown below. Of these, the time spent with ENCOR and TEMSE are quite significant factors for this study.

Table 3.3.A: List of volunteer controllers with descriptive elements.

| **Aspects** | **Controllers** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C 1 | C 2 | C 3 | C 4 | C 5 | C 6 | C 7 | C 8 | C 9 | C 10 | C 11 | C 12 | C 13 | C 14 |
| **Position** | | | | | | | | | | | | | | |

| **held:** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power System manager | X | X | | | | | | | | | | X | | |
| Senior advisor | | | | | | | | | | | X | | | X |
| Commissioning Controller | | | | | | | | | | | | | | |
| Senior controller | | | X | X | X | X | | X | X | X | | | | |
| Controller | | | | | | | X | | | | | | X | |
| **Race:** | | | | | | | | | | | | | | |
| Black | | | | | X | | X | X | | | | X | X | X |
| White | X | X | X | | | | | | X | X | | | | |
| Indian | | | | | | X | | | | | X | | | |
| Coloured | | | | X | | | | | | | | | | |
| **Years of experience:** | | | | | | | | | | | | | | |
| 1-2 | | | | | | | X | | | | | | X | |
| 3-5 | | | | | | X | | | | | | | | |
| 5-10 | | | | X | | | | | | | | | | |
| 10+ | X | X | X | | X | | | X | X | | X | X | | X |
| **Gender:** | | | | | | | | | | | | | | |
| Male | X | X | X | X | | X | X | | X | X | X | X | X | X |
| Female | | | | | X | | | X | | | | | | |
| **Age:** | | | | | | | | | | | | | | |
| 20s | | | | | | | X | | | | | | | |
| 30s | | | | | X | X | | | | | X | | X | |
| 40s | X | X | | X | | | | | | | | X | | X |
| 50s | | | | | | | | | | | | | | |
| 60s | | | X | | | | | | X | X | | | | |
| **Qualifications:** | | | | | | | | | | | | | | |
| 2 year NQF 5 | | | X | X | | X | | | X | X | | | | |
| 3 year NQF 6 | | | | | X | | X | | | | | | | |
| 4 year NQF 7 | X | | | | | | | X | | | | X | X | X |
| 5 year NQF 8 | | X | | | | | | | | | X | | | |
| **ENCOR and TEMSE experience** | X | X | X | X | X | X | | X | X | X | | X | | X |
| **No TEMSE experience** | | | | | | | | | | | X | | | |
| **No ENCOR experience** | | | | | | | X | | | | | | X | |

Most (12 / 14) of the controllers have had many years of experience with the ENCOR displays. This means that they learned everything they know about the Eskom transmission network off the ENCOR screens. As the process of working within the control room involves stressful periods of work and the consequences of operating errors are quite severe one can assume that the ENCORE images might be well embedded in their minds. Two controllers have had no ENCOR experience and therefore their feedback about working with the TEMSE displays is not in conflict with any previous mental images acquired from ENCOR. Also two other controllers have not worked with the TEMSE system as they have moved out of the control room. They were included in order to see if there is anything we can learn from their experience. The ENCOR system required two-hand operation. TEMSE only requires one hand to operate the mouse, which is the main instrument to effect control and monitoring actions.

## 3.5 Overall Impression of Participants

In this section a summary of the overall impressions, which the interviewer formed, of the fourteen controllers, is presented. These impressions are given here in order to set the tone for the type of responses provided. It is quite important to note that there is an overall culture among the control room staff, and in many ways they are quite isolated in their world of shift work and high stakes. Very few members of the public, even other Eskom employees realise the tremendous contribution that these few persons make, and the hidden difficulties, which they face on a daily basis.

During a recent visit to the NCC, members of the South African Engineering Council (ECSA) were impressed and awed by the level of complexity of the work performed and the required expertise levels of these controllers, as compared to other industrial environments in SA. The table below was created considering the factors that individuals can have an impact on. These are: **People** (+ve/-ve attitude), **Ability** (high X), **Interest** to be involved **in Management** issues (Yes +, NO -, or indifferent)

Table 3.4.A: Overall impression of each of the participating controllers

| Controller | Overall Impression | People (+/-) | Ability | Management |
|---|---|---|---|---|
| C1 | Confident, motivated, takes initiative on many levels, considers the views of others strives for consensus in the control room, good mentor, studied further | + | x | + |
| C2 | Confident, motivated, takes initiative on many levels, moves ahead, requires new challenges, has moved out of the control room, cares for others, studied further | + | x | + |
| C3 | Quiet, withdrawn, not very expressive, intelligent, resigned, says he is ok but does not seem enthusiastic, has not studied further, did not contribute much in terms of tacit content even though when asked about the mental imagery in his mind and whether it resembles TEMSE or ENCOR he said TEMSE yet also said that he does not have any mental images | - | | - |
| C4 | Enthusiastic, participated openly, confident, looking to move on, has studied further, aspires to teaching, or something outside NCC, family important. | + | x | + |
| C5 | Was tired and apprehensive at first but looked really well at the end, spoke well, contributed freely, has aspirations to work outside the control room, under pressure from having a daughter (single parent), does not aspire to move up in the NCC stucture | - | | - |
| C6 | Quite enthusiastic, curious | + | | |
| C7 | Motivated, enthusiastic, interested in the wellbeing of others, informal, friendly, initiates new ventures, engages with the work, contributes freely, able to describe internal experience, inclusive leadership qualities | + | | + |
| C8 | Confident, motivated, eloquent, contributes freely and in detail about her inner experience, studied further, and wants to do even more, in and out of control room experience, system expert. | + | x | + |
| C9 | Sincere, tries hard, frustrated, frightened, willing, considerate, knowledgeable, holds back out of concern for consequences, no further studies | + | | - |
| C10 | Confident, humorous, considered, no further studies, very kinaesthetic, metaphors for working, not very detailed in descriptions, “old hand” | + | | |

| | | | | |
|---|---|---|---|---|
| C11 | Directed, ambitious, competent, creative, studied further, independent, considerate, gets things done, willing to participate, defiant, high aspirations, high self worth | + | **x** | + |
| C12 | Quiet, relaxed, initially guarded then contributes freely, would like to study further but needs support, steady, | + | | |
| C13 | New, motivated, determined, vivid imagery, engaged, ambitious, plans ahead | + | | |
| C14 | Humorous, determined, can become confused at first, studied further, settled in his level, interested in others | + | | |

It can be argued that the attitudes the controllers exhibit must either contribute to or inhibit performance. The controllers who participated are a fair spread of the type of person that works in the control room, however there may be some who did not participate, that have tendencies that fall in the non-conducive group of attitudes, which by definition would prevent them from participating.
From all the above most of the controllers demonstrated a positive attitude (12 / 14).
Less than half (5 / 14) demonstrated high levels of ability.
(6 / 14) controllers demonstrated an interest to impact on management processes positively, (3 / 14) negatively, and (5 / 14) were neutral or resigned toward management processes.

Overall it would seem that the controllers in this group were competent and willing to engage with their work environment in varying degrees. It also seems that given the opportunity to make explicit their strengths and weaknesses there will be great scope for improvement at all levels of their working experience. It is my sincere hope that management, in particular, will invest in the required resources to make this happen.

## 3.6 The Network Simulator Exercise Details.

The controllers were given a task to perform on the network simulator at the NCC, which is adjacent to the control room. Inside the simulator room there are computer monitors

and a wall display of the whole of the transmission network, similar to what is inside the main control room. The monitors display the same TEMSE network format, network data, and network status information off the actual values from the control room next door. However the control actions performed on the simulator have no effect on the network itself, instead, the simulator software performs the required calculations in order to reproduce system responses to each control action. Each controller used two computer monitors to view system data, which consisted of lists of system voltages and substation bus-bar schematic layouts as per the TEMSE system layout. The controllers did not refer to the wall network display during their work. This is similar to how they work in the control room. The wall display is mainly used for starting up the network in case of a black out.

For the research project a contingency case was created which involved three back-to-back incidents in a central part of the network. Details of this case cannot be disclosed due to security reasons. However the three contingencies were as follows:

1. First, two parallel lines between two sub stations tripped
2. Second, one of three transformers in an adjacent sub-station tripped
3. Third, the other two transformers of the above substation tripped

In each case, the controller on the desk had to make sure that the system transmission voltages were maintained at the required level by:

- Activating voltage control equipment (Capacitor banks, SVCs, etc.)
- Rerouting reactive power flow (switching lines in and out)
- Requesting or delivering reactive power from / to generation sources
- Performing load shedding (of contracted customers, and other loads)

To achieve all the above the controller on the desk would use the computer mouse to control the required equipment or ask for various functions to be performed by persons out in the field or in power stations. Simulator training staff were on hand to stand in for the required field staff. They carried out the last two functions for the purpose of the simulation.

The total exercise was completed in an average time of about fifteen minutes by each controller. Twelve out of fourteen controllers did not manage to maintain the network voltage levels, as the case was designed to lead to system collapse. Those who did manage to contain the system voltages did so by extensive load shedding in areas of the network linked to the contingency areas. The controllers' actions were video recorded for the duration of the exercise. Portions of the recording were played back to each controller at the starting point of the interviews, which followed, in order to elicit the information required by the research question.

## 3.7 The TRVP Procedure: What Was Elicited, and the Methods Used.

After the simulator exercise was concluded the following were elicited by various means as described below. The main area of interest as per the research question was the tacit domain of the controllers' minds. However in order to get to that information a number of preliminary and / or auxiliary steps were taken in order to get to that point as follows:

1. First, the controllers were asked to write down what happened during the exercise in their own words taking as much time as they needed. This was done in order to create a reference of the degree of disclosure that each controller was spontaneously capable of producing on his / her own. Needless to say there was no tacit information presented in these written reports. Each was left to their own devices to put down whatever they wanted. Some wrote long descriptions full of detail while others only wrote down a few lines. The purpose of this step was to discover the level of internal (mental) processing awareness in the controllers' conscious perception of the events.

2. Then the main interview process followed. The purpose of these interviews was to identify what takes place in the minds of the network controllers at the NCC when they work with the new Windows-based TEMSE computer displays. These displays have replaced the previous ENCOR displays and being Windows based

have different functionality and similar appearance (as shown in Appendix C). The stages of the interview were: Building rapport, viewing video from the simulator exercise, questions in order (as described in Metamodel and Sub-modality elicitation techniques described below), and closure (as described in "values" below). The formal interview session, which took about two hours for each person, was conducted immediately after the writing step. First, a part of the video footage just taken was played back to the controller so that he / she could view themselves working on the simulator and thus describe what they were doing, as well as what they were thinking at the time. The part of the video played back was taken from the latter part of the 15 minute exercise where the main faults had occurred on the network, as by then the controllers were "in character", visibly experiencing intense emotions, and were fully immersed in the experience. They were then required to introspect and describe the tacit elements of their experience as prompted by the NLP question techniques. At the end of the interview the controllers reported that they enjoyed the opportunity to view themselves work and delve into the tacit domain. They emphasised that they learned a great deal from the whole exercise.

3. During this phase "Metamodel" questions (Grinder, 1975) as well as Sub-Modality (Bandler, 1988) questions were used to elicit the controllers' tacit mental experience. These techniques are explained in the literature review section. By means of the Metamodel questions the implicit meaning of their descriptions were investigated. For instance when someone said "there is a section of the network…" the researcher would enquire, "Where is it in your mind? Front, back, to the side etc." Then by means of the sub-modality questions, the internal (visual, auditory, and kinaesthetic) representations, which had spontaneously arisen in their minds (in response to what was presented on the computer displays) were investigated. During this phase they were specifically asked to compare the images arising in their mind to the images appearing on the computer monitors. Then, they were asked to report about the quality and appearance of the mental images and whether they resembled the ENCOR or TEMSE formats. This part is

where the Tacit Retrospective Verbal Protocols (TRVP) were elicited, as the main thrust of the research; they represent an extension of the standard RVP, extending its scope and depth. The revelation of the tacit dimension of processing opens up new vistas for research and training within the NCC environment and any other similar working environment around the world.

The controllers' attention was guided gradually toward the tacit domain in stages, from the conscious realm to the subconscious, as this is not something that they were used to doing. The following were elicited in the order shown:

- **Written feedback (conscious):** How the controllers described what happened during the simulator exercise in their own words without any input from the interviewer.
- **Feelings / Emotions (borderline):** How they felt during the exercise. The purpose of this step was to assist each controller to turn their attention inward, away from the events outside, by first identifying the sensations and emotions as they emerged in their body during the exercise. In this way their attention was gradually turned toward the tacit domain.
- **Tacit Content (subconscious):** The tacit mental representations. This was achieved by means of the techniques described in the literature review under Metamodel (Grinder and Bandler,1975) and Sub-modality (Bandler and Macdonald, 1988) techniques.
- **Tacit Structures (subconscious):** The tacit sequences and structure used by the controllers while working on the simulator. This was achieved by means of the same techniques.
- **Adjustments (subconscious/conscious)** made by the controllers as they changed over from ENCOR

  to TEMSE. *After* the controllers were made aware of tacit phenomena they were asked to identify what were the main adjustments that took place in that domain as a result of the changeover. They were also asked to estimate how long it took them to adjust to the new TEMSE system.

- **Other Important factors (conscious)** that foster or inhibit controller performance inside the control room.

  Tacit phenomena rise to conscious awareness (after being triggered by environmental or internal stimuli) (Pinker 1999, Anderson 2002, Ramachandran 1997, Bandler & MacDonald 1988). It was therefore important to identify any factors, which enable, inhibit, or distort, the activation of tacit phenomena and thus impact on controller performance. Questions relating to matters outside the scope of the research questions were asked in order to identify the broader context around the arising of tacit phenomena. The controllers were asked to identify which of the following factors were the most important for them within the control room environment. This is another way of saying that it was necessary to identify which external factors enable the tacit expertise sequences and which factors inhibit them. Because these factors trigger tacit responses, the controllers reported that certain factors were the "cause" of good or poor performance, as if they were powerless under the influence of invisible forces. These included the influence of:

  - **People** (individuals, relationships, shift dynamics, management support, etc.)
  - **Equipment** (type and quality of interfaces, other equipment, etc.)
  - **Knowledge** (Technical knowledge and training)
  - **Environment** (The control room itself, lighting, heating, etc.)
  - **Conditions** (Conditions within the control room, day / night shift etc.)
  - **Prospects** (Promotion requirements, career prospects, etc.)
  - **Requirements** (Requirements from others like staff, management, the job itself, etc.)
  - **Internal factors** (Abilities, beliefs, values, identity, purpose, mission, other)
  - **Other areas of their life** that have impact or play a significant role in your work at national control and how (like family etc.)?

- **Value:** The controllers were asked if they found this whole process of value to them. At the end of each interview session the controller being interviewed was asked how they felt about the process itself in order to identify further benefits and training interventions which could be introduced.

It became evident during the interviews that the controllers who were not exposed to the idea of the tacit domain were not consciously aware of their mental strategies and visualizations. This in itself proved to be quite a significant benefit / finding, as this new discovery opens up avenues for further training and development. The preconditions for the interviews were:

- All the participants were volunteers.
- There were no preliminary discussions with the controllers prior to the interviews. The context given to them was that they would be given a task to perform on the simulator and that they must do the best they can. Most of them initially thought that they were being assessed on their ability to restore the network after the contingencies.
- The simulator sessions provided the opportunity to deeply engage them and reveal the mental skills and imagery they elicited. It is important to note that the simulator sessions were successful in producing a real "working emotional state" within each one of the participants as if they were in the actual control room, under contingency conditions. This is evident on the video recordings as well as by the controllers' own descriptions, during the interviews. The presence of the video cameras also added to the intensity of the experience, as monitoring seems to heighten one's experience. This can have a performance enhancing or performance inhibiting effect.
- The formal interviews that followed immediately after the simulator work, took the process deeper so that the elicitation of the tacit components could be completed. The need for time during the last stage of the interview process is of paramount importance as the ground covered was unfamiliar to the controllers. Most controllers mentioned that they had never thought about

mental imagery and tacit representations. To overcome this barrier, casual conversations were initiated on the topic of their performance on the simulator. It was the interviewer's job to spot moments where the person interviewed was processing information at a deeper level by means of facial expressions, hand movements, eye movements, etc. and then ask them to notice and report about it. In this way, they became aware of and were able to report on the vivid tacit imagery and mental processes underpinning their performance. These are recorded in the findings section. The book by Bandler and Macdonald (1988), provides vivid accounts of similar elicitations.

- The complete process was video recorded.

4. At the end of the interview each controller was given three copies of a list of emotion bi-poles, as obtained from Shalif (2004), (arranged with a seven-point scale with zero in the middle, for each bi-pole) shown below.

THE FOLLOWING IS A LIST OF THE 15 BASIC EMOTIONS PRESENTED TO THE CONTROLLERS:

**NAME:** **DATE:**

| | | | |
|---|---|---|---|
| 1) Contentment | **(Pleasure** | **3 2 1 0 1 2 3** | **Sorrow)** |
| 2) Concern | **(Love** | **3 2 1 0 1 2 3** | **Hate)** |
| 3) Security | **(Fear** | **3 2 1 0 1 2 3** | **Serenity)** |
| 4) Play | **(Seriousness** | **3 2 1 0 1 2 3** | **Frolic)** |
| 5) Belonging | **(Attachment** | **3 2 1 0 1 2 3** | **Solitude)** |
| 6) Will power | **(Volition** | **3 2 1 0 1 2 3** | **Surrender)** |
| 7) Energy | **(Rigor** | **3 2 1 0 1 2 3** | **Flimsiness)** |
| 8) Frustration | **(Anger** | **3 2 1 0 1 2 3** | **Leniency)** |
| 9) Involvement | **(Interest** | **3 2 1 0 1 2 3** | **Boredom)** |

| | | | |
|---|---|---|---|
| 10) Self-Respect | **(Pride** | **3 2 1 0 1 2 3** | **Shame)** |
| 11) Eminence | **(Superiority** | **3 2 1 0 1 2 3** | **Inferiority)** |
| 12) Respect | **(Adoration** | **3 2 1 0 1 2 3** | **Scorn)** |
| 13) Vigilance | **(Wariness** | **3 2 1 0 1 2 3** | **Dreaminess)** |
| 14) Expectancy | **(Surprise** | **3 2 1 0 1 2 3** | **Routine)** |
| 15) Attraction | **(Disgust** | **3 2 1 0 1 2 3** | **Desire)** |

They were then asked to score the intensity, on each seven-point bi-pole scale, that they experience inside the control room for each of the fifteen emotions on the list, under the following conditions:

- **Working in the control room under quiet late night conditions.**
- **Working in the control room when there is a contingency, which they face alone.**
- **Working in the control room during a contingency, which they face with support from other controllers.**

The second question is about how they feel when faced with a contingency inside the control room, which they have to face alone. This is very close to what they had to face in the simulator exercise, where the contingencies were presented to them alone. In this way the emotions referred to on paper and the ones mentioned verbally should compare closely with each other if the two experiences are similar. In order to avoid pre-empting their responses, the controllers were not asked directly if their emotions in the control room and the simulator correlated. The three scenarios presented to them were left for them to interpret. **This fact must be emphasised as it lends credibility to the findings.**

## 3.8 The Methods of Analysis.

In this section are presented the relevant aspects of the information, which was extracted from the research procedures, as well as how these relevant points were analysed and commented upon.

### 3.8.1 Analysis of What they Wrote.

The information that the controllers wrote about what happened during the simulator exercise was summarised in five categories from the least close to the most close to the tacit domain. The more the information is about self, the closer it is to the tacit dimension and visa versa, in the following order:

- What Happened (least tacit)
- What Happened / What they Did
- What they Did / What Happened
- What they Did
- Internal processing (most tacit)

The results were tabulated as follows:

| Controller | Information (Attention emphasis while reporting what happened) |
|---|---|
| | |

The findings from this table were then expressed in % terms and discussed.

### 3.8.2 Analysis of the Findings of the Emotions Section.

The information gathered during this phase takes us a step closer to the tacit dimension. The reports given by the controllers are classified as follows:

- A summary of the key emotion words reported by the controllers as they recollected them during the interview after the simulator exercise was tabulated.
- Secondly, these emotion words were compared with the emotions the controllers reported having while dealing with a contingency in the control room, when they were all alone, as they were in the simulator. This information came from the second form they completed in response to the question: How do you feel when working in the control room when there is a contingency which you face alone?
- Then the correspondence of the two was Confirmed or Not confirmed, and comments were made where there was a difference.

The table used was like the one below.

| Controller | Emotions / Feelings Information | Comparison |
|---|---|---|
| | | |

The findings from this table were then expressed in % terms and discussed.

### 3.8.3 Analysis of the Findings from the Section on Tacit Content.

The process consisted of first transcribing what the controllers said; then sections with direct reference to tacit visual and auditory content (such as mental images, their mental location, colour, or voices, their intensity etc.) were highlighted in different colours and extracted. Then these sections were summarised focussing on the key descriptor words. In this way the information provided by the controllers about the tacit content of their experience, was extracted, simplified, and tabulated as shown below. Under the comment section a summary of what was presented in the Information column was created.

| Controller | Information (Tacit Content) | Comments |
|---|---|---|
| | | |

Then the information was analysed to identify the following points:

- Were there mental images?
- Were they in colour, or black and white?
- Were they simpler than the images on the computer displays or as complex, and were there any other mental depictions like maps etc.?
- Did they resemble the ENCOR or TEMSE displays?
- Were these images used to "navigate" the contingencies?
- Was there a prominent inner voice (auditory) component to the tacit experience?
- How many elements (power lines etc.) were included in the mental images as presented in the sketches the controllers produced?

These findings were tabulated as well as shown below.

| Controller | Images | Colour | B &W | Simple | Complex | ENCOR | TEMSE | Used to Navigate | Inner voice | Sketch lines / elements |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

The findings from these tables were then expressed in % terms and discussed.

### 3.8.4 Analysis of the Findings of the Section on Tacit Structures.

The term Tacit Structures refers to the sequences, which the controllers followed in doing their work, such as looking at the computer screens, then seeing mental images, followed by internal verbalisation (thoughts), then carrying out some action, etc.
These sequences were identified and compared in order to find out what were the trends, if any, and what they reveal.

First the findings from each controller were summarised as follows.

| Controller | Information (Tacit Structures) |
|---|---|
| | |

The most important factor is whether the controllers were capable of maintaining an unfettered state of awareness, because when a person's attention becomes "stuck" then their ability to continue functioning is diminished to a great extent, or is absent. It is this skill, which is paramount in this section.

Another key factor is the ability of the controllers to consciously engage with their mental visualizations, and in particular their ability to "zoom" in and out of the mental images they had of the network. This skill allows for flexibility of a different kind, it is the flexibility of decision-making. That is, with the ability to see the big picture and consider as many operating options as possible within the constraints of a contingency (such as area, time, equipment states etc.) *then* zoom in to operate, control strategies and opportunities for maintaining system integrity could be optimised.

Then the inhibiting factors that prevent the controllers from maintaining a free attention were considered, such as an internal verbalization(s) leading to attention break down and the associated unpleasant feelings they evoke.

The following symbols were used to create the representation of the tacit sequences:

Looking externally to the person, (Ve) stands for Visual external.

Seeing mentaly, (Vi and / or Vizo, Vizi) stand for Visual internal and / or zoom out, and zoom in, mentally.

Hear Thoughts (T)

Fear or calm (K- or K+), stand for Kinaesthetic –ve and +ve.

Work on the network (W), stands for using the mouse and the computer displays to do something on the network.

Attention flexible or stuck (ATTf or ATTs).

The above terms were extracted from the transcripts of the interviews and tabulated to map the sequences of events that a controller followed i.e. seeing externally, visualising internally, looking outwardly again etc., as shown below.

| Controller | Sequences of Tacit Structures | Attention state |
|---|---|---|
| C1 | Ve-Vizo-Ve-Vizi-T-Ve-W- (K-)-Vi-(K+) | ATTf |

The findings from this table were then expressed in % terms and discussed.

### 3.8.5 Analysis of the Findings from the Adjustments Section.

In this section the information pertaining to the transition from ENCOR to TEMSE is summarised. The controllers' comments on how long it took them to adapt from ENCOR to TEMSE, the type of adjustments they found the most difficult, and any other comments about the two systems are tabulated at the end of the section.

The findings were tabulated as follows. The Other Comments part includes particular comments that the controllers made about particular aspects of the adaptation process like colours used on the displays, diagram size, response speed of the HMI, etc.

| **Controller** | **Years of experience ENCOR / TEMSE** | **Transition time ENCOR to TEMSE** | **Adjustments** | **Other Comments** |
|---|---|---|---|---|
| | | | | |

The findings from this table were then expressed in % terms and discussed.

This was followed by a list of positive and a list of negative comments about the TEMSE system, which the controllers made during the interviews.

### 3.8.6 Analysis of the Findings from the Section Other Factors.

First the findings were summarised as follows.

| Controller | Work Enhancing Factors | Detrimental Factors |
|---|---|---|
| | | |

Then the findings were ordered as per the order of importance, which emerged from the analysis, in a table as follows. The more controllers commented about a topic the higher was its order of importance.

| Controller | People | Knowledge Experience Ability | Equipment | Environment | Family | Prospects | Management | Communication | Requirements | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

The findings from this table were scrutinised and discussed.

### 3.8.7 Analysis of the Findings from the Was This Useful Section.

In this section the controllers' responses regarding how they felt about the whole process were summarised as follows.

| Controller | Was This Useful | Comments |
|---|---|---|
| | | |

The findings from this table were scrutinised and discussed.

## 3.9 Equipment Used

The following equipment were used to conduct the research:

1. The **TEMSE simulator equipment** in the simulator room.
2. **Two monitors and a PC with a keyboard and mouse.** The TEMSE system simulator software was loaded on the PC. The controllers used this setup to work on the Eskom network using the TEMSE format of display and control. This equipment is permanently installed in the simulator room at the NCC.

3. **Two digital video cameras using mini DV tapes.** One camera was used for recording the controllers during the simulator exercise and to play back their activities on the simulator during the interview where the TRVPs were elicited. This camera captured their upper torso as well as the computer monitors in front of them. It was positioned on a tripod to capture a side view from the left.

   A second camera was used to record the interview itself as the first camera was also used to playback the simulator exercise footage. This camera was also on a tripod and was focused on each controller head on, capturing their body from the waist upward, particularly their arm movements and facial expressions.
4. **One data projector.** This was used during the interviews to play back the video footage from the first camera (of the controllers working on the simulator) in order to prompt the interview discussions and the elicitation of the TRVPs.
5. **A laptop computer** for capturing and storing all the information.

## 3.10 Ethics

This was a study commissioned by Eskom and the research was conducted from archival data, which will not be made available to unauthorised persons.

### 3.10.1 Anonymity

The list of the controllers' names will be kept confidential. Reference was made to them by numbers only i.e. controller 1, 2, etc., the order of numbering was random. Only the researcher knows which number corresponds to which controller. The NCC training manager may be able to infer who some of the numbers represent but that would be difficult even for him, as there is more than one controller in each category. The individuals who took part in the research did not object to the information they disclosed to be made public, when asked during the interviews. Some even wanted to make statements "for the record" regarding NCC working condition related matters.

### 3.10.2 Participation

Eskom commissioned this research and it was cleared by the NCC management, for content as well as other security related maters, because the NCC is a key national security environment. However even though the research was sanctioned from the top, all the controllers were asked if they wanted to participate and only those who responded positively took part. They were all volunteers. No one was required to participate if they did not want to. If a controller refused to participate when asked, they were left out from the final list. There were no benefits or penalties associated with participation or abstention. The ones who did participate did derive the benefit of the process itself but that was entirely unrelated to any job benefits. Each controller gave of their own time during days for which they were off shift work and were at the NCC for training purposes, as required by their conditions of employment agreement.

### 3.10.3 Confidentiality

Confidentiality was guaranteed at the outset and has been maintained throughout the process. The video material will be kept in the custody of the researcher for future reference, and will not be released to any one. Not even Eskom staff.

### 3.10.4 Feedback

Feedback was given to each controller during the sessions about his or her tacit content and processes. In some cases, as reported in the results section, controllers were coached to try out new cognitive skills, like mentally zooming in and out of their mental images, which they found very beneficial. The thesis itself will serve as official feedback to Eskom management and will be circulated to the participants at the NCC.

# Chapter 4:

# RESULTS

In this chapter the results obtained after conducting the simulator exercise, i.e. the subsequent written reporting, and verbal interviews, mentioned in Chapter 3, are presented, and analysed in a consolidated form. See **Appendix D** for the extended results.

## 4.1 Introduction

It would be appropriate to start by quoting some of the controllers whose statements seem to capture the essence of the reason for conducting this research.

“I made a list of all the factors that lead up to an incident where a controller made an operating error. Is it lack of training, is it lack of sleep , etc… ?

The single common problem from all these areas is communication.

It can be communication between two guys working on the same thing, or from control room to control room, or with some one out on the field. In nine out of ten incidents it’s communication. There is this expression, ‘Deaf as those who do not want to hear’.”

In the context of this research the last sentence can be rewritten as, “deaf as those whose attention is imprisoned by their own thoughts which they are not aware of.” In this research it’s the quality of the communication that we are interested in, as the tacit detail, which emerged from the interview process, opens up a whole new level of information that can be communicated. When communication between two people includes that level of detail the quality of what is communicated increases, because the tacit detail in both people’s minds can be crosschecked for correlation. Otherwise in the process of communication each person can become engulfed in his or her own reality as created by tacit imagery etc. such as to totally misunderstand the other person. This phenomenon was aptly described by another controller who said, at the end of the interview process, “This process also helps and assists as part of conflict resolution, … not long ago we were arguing (a person off shift and I) about something that happened, that I never did

that (during an incident)… later I checked the voice recorder and I realised from the first word that I had not heard what he was saying, because my mind went to a previous issue…if I had given him a moment to listen to him, to ask a few questions and get what he wanted, … we were not talking about the same thing… we were talking about a different time window,… and now I realised I was not arguing about the same thing."
This is a classic example of one person being lost in tacit imagery and not being able to register what the other person is saying. And finally as another controller put it, when he became aware of the tacit images in his mind during the interview, "Its amazing, now as I think of it, … this is what happened the whole time, but I didn't say it, it's a simple picture (in my mind), but just the backbone, it shows how its linked back… this is a simple (mental) image of what I saw when there was a problem… and it was highlighted (in my mind) the whole time… that is how you know where to go the whole time! Where you can improve your voltages."

It seems quite clear from the above statements that the tacit realm, as defined in the Background chapter, underpins everything that goes on in the control room. In the first quote it is "implied" in the word "communication", in the second and third quotes it was made explicit by the controllers, after they had undergone the interview process, which assisted them to pay attention to the tacit domain. As was stated in the introduction, the contribution of this research is to reveal the tacit domain of the NCC controllers' minds with respect to the HMI displays, and thus some of the hidden forces, which underpin their skill base. This is in order to facilitate improved work performance in the real world of Power System Control, and by extension to expand the possibilities of RVP analysis techniques by creating the TRVP.

## 4.2 Categories of Results

After the controllers had worked on the simulator the following categories of information were elicited, summarised and analysed:

**A. Written Feedback:** The controllers described what happened during the simulator exercise in their own words, in writing, without any input from the interviewer.

**B. Feelings / Emotions:** How the controllers felt during the exercise and how that compares to what they feel inside the control room under real working conditions.

**C. Tacit Content:** The tacit mental representations, which arose while they were working on the simulator.

**D. Tacit Structures:** The tacit and explicit sequences and structure used by the controllers while working on the simulator.

**E. Adjustments:** The adjustments made by the controllers as they changed over from ENCOR to the TEMSE system of computer displays.

**F. Other Important factors:** Other important factors that foster or inhibit controller performance inside the control room.

**G. Value:** The controllers were asked if they found the whole interview process of value to them.

The findings and analysis of each one of these sections are presented here in a coherent narrative. In this, all the aspects of the information gathered and their interrelations have been integrated into a coherent whole. Also the means of expanding the RVP methodology to the TRVP will become apparent and will be discussed.

Note: The interviewer is indicated as “Int” and the controllers are indicated by “C1 to C14”.

## 4.3 Consolidation of Findings

As the Results chapter consists of a number of sections, each one with its own set of results, the information obtained from each one of them is presented below in a consolidated form. **Please note that some paragraphs are purposely reproduced verbatim compared to what is presented in APPENDIX D, for continuity and completeness. The full set of results, i.e. the verbatim responses of the controllers to the interview questions, a detailed summary, and analysis of the results, are presented in APPENDIX D.**

As the research process progressed, a set of impressions was formed about each controller as they began the process of working on the simulator and then participating in the interviews. There seemed to be some common elements in the way the controllers behaved and responded. Most of the controllers seemed to have a positive attitude (13 / 14) and seemed engaged with their work. Their attitude toward management and operational issues within the control room seemed to fall within three groupings. Those who wanted to impact on the processes and management issues, (about 43%); those who did not want to be engaged at all in such matters, about (22%); and those who did not seem to care one way or the other (about 35%). Of the fourteen participants five (about 35%) stood out as having a high level of skill in dealing with contingencies. The rest seemed to be in two groups, those who are new and therefore still growing in expertise, and those who have settled into a particular slot or level of competence, which is regarded as a sort of ceiling. The interview process may have opened up possibilities for growth for all, as each one became aware of the hidden forces, which limit or enhance performance. For instance the ability to mentally zoom out and see large sections of the network was a very significant skill as will be discussed below.

Most (12 / 14) of the controllers have had many years of experience with the ENCOR displays. This means that they learned most of what they know about the Eskom transmission network off the ENCOR screens. As the process of working within the control room involves long periods of calm followed by stressful periods of work, and the

consequences of operating errors are quite severe, one can assume that the ENCORE images are well embedded in their minds together with powerful emotions which condition reflexes due to tacit structures in each person's brain. As a result, to change over to the TEMSE displays was quite a process for each one of them (Muller, 2010). As this consolidation narrative develops it will become apparent how long it took them to make the transition to the TEMSE system and what happens to the tacit network representations in their minds under contingency conditions.

### 4.3.1 **Written Feedback** of what happened, prior to the interview process.

In their initial written feedback there was no mention of tacit phenomena, but 35% of the participants did allude to mental aspects of their experience, such as "I thought about … etc." This is a relatively small percentage and hopefully this situation will improve to include all of them now that they have been exposed to the interview process. The rest of the written comments (65%) were about what happened and what they did. The two participants who did not make any reference to self (wrote only about what happened) in their account are a minority in this group; these would perhaps be good candidates for further training. The writing down of what happened was the first step in the interviewing process and it only served as a reference of what may be the normal focus (outward, event, and action based) of each individual in the context of his or her work at the NCC.

### 4.3.2 How long it took to make the **Transition to TEMSE**

Two controllers had no ENCOR experience and therefore their feedback about working with the TEMSE displays is not in conflict with any previous mental images acquired from ENCOR. The ENCOR system required two-hand operation, one on the keyboard and the other on the mouse. TEMSE only requires one hand to operate the mouse, which is the main instrument to effect control and monitoring actions.

Most of the controllers seem to have mentally made the transition to the TEMSE system, 43% (6/14) took between 1 – 3 months, 14% (2/14), took 6 -12 months to adjust,

7% (1/14) controller reported it took about 2 years to adjust to TEMSE, and 7% (1/14) one controller reported that he is still going through the process of adaptation. 14% (2/14) controllers reported that they have their own mental images therefore the transition did not influence these, and 14% (2/14) controllers reported that they did not have ENCOR experience so there was no transition time as they were new to the control room environment. As far as tacit imagery goes the one controller who reported that he still has ENCOR mental images could be assisted to also make the transition now that he is aware of the situation. Also, since 14% (2/14) of the controllers reported they have both TEMSE and ENCOR mental images, interventions could include them as well. The 57% (8/14) of the controllers who reported that they have TEMSE images in their mind could be used as references to identify how they made the transition and perhaps adopt their strategies for those who have not yet managed. The 14% (2/14) who reported that they have their own mental images, which are neither TEMSE nor ENCOR could be used to further investigate their expertise levels and perhaps develop alternative best practice strategies to further enhance performance for all.

The following difficulties with the transition were mentioned:
43% (6/14) reported having difficulties in making the transition, with one or more of the following:

- Mouse use
- Mental adjustments
- Alarm depiction
- Slowness of response of the TEMSE system
- Voltage value colours

Other than the mental image adaptations, which have been discussed above, the rest of the issues listed are to be addressed by HMI developers. It is interesting to note that 50% (7/14) said that they did not have any difficulty with the transition or did not have to make any major adjustments. It would be interesting to find out why that is so and add the findings to best practice protocols.

As far as the slowness of the TEMSE system goes it should be cause for some concern as information about best practice in this regard is available, as mentioned in the EPRI report of 1982, where it is stated that recommended response times are:

- 0.2 sec for the computer to respond to controller keyboard entries.
- 2 sec for operations between the controller and the system.
- Longer than 2 to 5 sec response times were found to be disruptive for interactive situations but were fine for complex computer processing of a request by a controller (even longer than 5 sec.).
- 5 to 15 sec responses (provided that within 2 sec a message is received to confirm receipt of request) are suitable for complex problem execution requested by a controller.
- Greater than 15 sec intervals are only suitable for performance of extremely complex routines.

This therefore is another issue that could receive attention, as even though the times above were identified some time ago, the reported slowness of the TENSE system leaves some cause for concern, as one would expect that computer response times would be faster at present.

On the positive side TEMSE can perform more functions, provide information about loadings, line limits, etc. quickly by using the mouse, there are no keyboard commands to create confusion, it shows a lot of information on one page, and offers better options.

### 4.3.3 Emotions

The feelings, physical sensations, emotions and any other relevant sensory experiences, which were elicited during the simulator exercise, were found to correlate very closely to the controllers' experience within the control room itself. This was achieved by comparing written information they provided about how they feel inside the control room during a contingency they have to face alone, like the one in the simulator, with the statements about how they felt during the simulator exercise. 92.8% (13 / 14) of the controllers produced written evidence that what they experienced emotionally in the

simulator was very much the same as what goes on in the control room. This finding goes a long way to reinforce the view that what they experienced in the simulator was “real”, and what they described as their tacit experience was real too. In other words if they were subject to strong emotional states, which are produced by forces out of their conscious control, their reports of the qualia-rich imagery (Ramachandran 1997) that underpins these experiences could also be the same as what they experience inside the control room. The richness of the qualia content of the controllers’ descriptions is what distinguishes them from simple rationalizations and speculation and classifies them as true reports of tacit experience (Ramachandran 1997). It is in this way that the emotional states they described lend credibility to their tacit descriptions, as it can be implied that the tacit responses by the controllers’ brains involve the same “circuitry” as when real contingencies occur.

The controllers used very strong terms to describe their emotions like, “panic, urgency, “very strong resistance from myself”, mild fear, “in the zone”, light, alert, not comfortable, “unfinished business” feelings, “this is too much”, conflict, scared, “breaks you up”, fidgeting, tense feeling, scared / tense, uncomfortable, “going down hill to the black hole”, worse and worse, “want to give up”, that loser feeling, “want to give up”, “you can’t give up, you have to fight it”, quite scary, tangled, stuck, nervous inside, “I feel I have to do something”, heavy, strain, more scared, strong feelings, urgency, some fear, high intensity, frustration.” Considering that the emotions and feelings described above are quite intense, even though the work carried out was in the simulator, one can only imagine the consequences of having to live with such emotions and sensations inside the control room given that there is very little discussion about them. I believe that this aspect of the controllers’ experience should be studied further as there have been instances of severe stress symptoms demonstrated in the past. In contrast, after the network was brought under control (for those who managed it) statements like “Now I feel much more relaxed” were used.

### 4.3.4 **Tacit Content:** Images and auditory mental content.

The information provided by the controllers about the tacit content of their experience, was extracted, streamlined, and analysed to identify the points listed in the tacit Content section, such as the presence of images, their colour, complexity etc.

In the results of the analysis 100% of the controllers reported the spontaneous arising of tacit imagery. Of these 93% (13 / 14) of the controllers reported their images either were in or included colour. Of these 21% (3 / 14) reported that they also had black and white images. All these images were simpler than the ones on the HMIs and 43% (6 /14) reported that they also had other complex imagery arising, like maps of the country, route maps, and actual images of places. The geographical images and route maps (Anderson 2002, p 122) were used to identify where equipment is situated and how the areas of the network work together. This type of information is not shown by the HMIs. However, images of the actual sub-stations, like “post cards”, acted as distractions.

Only one controller reported having ENCOR type images. This is quite an important finding as it shows that most of the controllers’ minds have made the transition to the TEMSE image format, however 21% (3 / 14) reported that they have both TEMSE and ENCOR images in their mind. The 57% (8 / 14) who reported that their imagery resembled TEMSE displays, seemed to have made the full transition. 14% (2 / /14) reported that they have their own mental images, which do not look like ENCOR or TEMSE.

All of them reported that they used the tacit mental imagery to “navigate” the contingencies in the simulator exercise. One said that he only used the HMI screens to navigate, but some of his other statements implied that he in fact had mental imagery which gave him direction, like, “There is more detail on the screen than in my mind, ... I know the basic layout and then I use the screen to go from there.” In some cases the mental manipulation of these images was a criterion of high levels of competence. Some of the other controllers (3 / 14) even tried doing this (zoom in and out) after the exercise,

and reported that it made a very big difference to how they could have dealt with the contingencies presented, and how they would have felt much better during the exercise as a consequence. Interestingly there wasn't any notable difference in the quality of the mental imagery of novice and experienced controllers (controllers C7 and C13 were relatively new to the NCC).

As far as auditory tacit experiences went 64% (9 / 14) reported that there was an inner voice (auditory) component to their tacit experience. This inner voice (s) played either a focussing enabling role, or had an inhibiting disturbing influence. For some this phenomenon (2 / 14) was very intense, with a number of voices going on at the same time. One other controller displayed behaviours during his working on the simulator of intense frustration, which he manifested verbally during the process as if he was expressing what was going on in his mind by saying things like, "I give up, … this is too much". We can surmise that it was quite likely that he also had internal auditory experiences as a result.

21% (3 / 14) controllers demonstrated that inner verbalizations affected them negatively. This means that as long as they had thoughts / words filling up their mental landscape, together with the emotions they evoked, there was no place for anything else. These emotions were of fear and frustration, which seemed to inhibit them cognitively and physically. This phenomenon (lots of inner dialogue) was observed with three controllers but it was less dramatic in two of them.

**This implies that verbal thought processes which flood a controller's awareness both inhibit his work and, I would suspect, create long term stress / strain problems. This last possibility could be monitored and its long-term implications assessed as a matter of urgency, as stress problems are quite common in the control room (Muller 2010).**

71% (10 / 14) produced sketches to illustrate their mental imagery. These images were simple and corresponded to their verbal descriptions. The images were of the affected areas and served as a "mental compass" to navigate the network during the contingencies. The shape, orientation, and features, of these sketches can be further

analysed to assist HMI developers in their designs. If computer display designs are made similar to what happens inside controllers' minds this may reduce response times and improve other elements of their performance, such as confidence, flexibility etc. It was suggested that the actual screen layout for each individual controller could be customised and they could select their layout when they sign in for shift work.

**All the above information leaves no doubt about the arising of tacit imagery in the minds of the controllers working at the NCC. The quality of these images and ease of their manipulation are some of the key signs of a high level of expertise. This fact can now be factored in when designing training and other interventions for performance enhancement. Further, the vocabulary used to describe these tacit images and structures, should become part of the everyday discussions in the control room in order to help controllers to expand their skills and learn from each other's inner experiences, which are what makes them stand out from other system engineers.**

### 4.3.5 Tacit Structures: Cognitive sequences used while working on the simulator.

After the existence and content of tacit experiences was documented, the cognitive *sequences* the controllers used to carry out their work were investigated. The sequences mentioned below are not related to the HMI displays per se. However it is important to note them, as they can be relevant to the development of cognitive best practice protocols. These sequences included looking at the screens, paying attention to mental imagery, experiencing intense emotions and other aspects of experience. From the results obtained in this section, it can be shown that what most of the controllers did is described by the following simplified symbolic sequence:

Ve – Vi – Ve – W – Vi - …

Where:

Ve: Visually see externally what is on the HMI monitors,

Vi: Visually see inside (mentally) to make sense of the situation and identify alternatives,

Ve: Visually verify externally on the HMI monitors,

W : Work on the computer to control the network,
Vi : Look inside (mentally) to see if the new situation is acceptable, etc.

This sequence was then repeated as required, with variations, until the situation was addressed one way or another. This is much the same as was pointed out by Pinker (1999, p60 – p62). Together with the above, the extra dimensions of inner zooming in and out, and thoughts (internal dialogue), were interspersed, which either assisted or inhibited performance. Another common factor in the sequence was the arising of intense feelings (pleasant K+, and unpleasant K-), which were dealt with in their own section, under the heading "Emotions", earlier. Unpleasant feelings (K-) are mostly motivators for action. However when they have to do with consequences to the controller they could be paralysing. In this respect the studies on stress, conducted by the Royal Navy in the UK (Bridger, 2007), can be of significance as it was shown that it's other people that are at the root of stress/strain symptoms, while working long hours mostly causes fatigue.

#### 4.3.6 **Attention** flexibility or fixation.

79% (11 / 14) of the controllers demonstrated that their attention was free to continue working, looking for ways to contain the contingencies. 21% (3 / 14) of the controllers appeared to be unable to continue in the face of what seemed to be an impossible situation, and their attention was "frozen" or stuck. An interesting phenomenon is recorded below and possible consequences arising from this are considered.

One of the controllers initially got stuck and could not continue with the work, as contingencies kept on getting worse. The same person however, after the exercise at the end of the interview, was able to change his state of mind to such an extent that he was able to find alternatives and sort out the situation without any difficulty at all. Now what was it that made this possible? It was the fact that it was put to him, "What would you do if there was no threat of reprimand if things got out of hand?" Suddenly his mind came to life and he was able to provide solutions to all the contingencies of the exercise. The sequence of his work sequences, before and after the suggestion, is captured in the relevant results section. Looking at the two sequences, the main difference is the great

deal of internal verbal processing (the tonality sub-modalities are very important here) going on in his mind together with powerful emotions. In this way even though the operators' mental models seemed incomplete, inconsistent, and unstable with detrimental consequences of poor visual momentum and cognitive tunnel vision (Thatcher 1995, p 109-119) initially, it was possible for him to step into a different state and perform his work well at the end. Given this example, one wonders how prevalent this phenomenon is, as similar (but not as intense) reports were provided by a few other controllers as well, off the record. Also, given the dramatic come back of the controller above it would be interesting to find out what possibilities for performance enhancement the reviewing of the existing regulations regarding penalization could create.

### 4.3.7 **Zooming in and out Mentally** to view larger sections of the network.

29% (4 / 14) of the controllers spontaneously reported that they would zoom out in their mind to see a broader picture of the network, in order to decide how best to proceed. Of these, one in particular did so consciously as a result of feedback given to him at an earlier time. On the other extreme, 21% (3 / 14) of the controllers got stuck mentally on a section of the network and could not proceed at all when the contingencies got to a certain point. Further, two of the controllers were asked after the interview, "What would happen if you would zoom out and see the whole network first, then decide what needs doing?" In both cases they reported that their skill level would be much higher and that they would have had alternatives from the start. In order for a controller to do this, they need to have a good mental image of the network, as well as to develop the ability to remain calm under contingency conditions so that they can mentally zoom out in order to decide what to do. This mental dexterity seems to be part of the "best practice" strategies used by some of the competent controllers. Another very important factor is the simplicity of the mental images as compared to what was on the HMIs. This finding seems to suggest that the controllers were able to assess the main aspects of a situation, as a whole, and take action as required. Together with emotional calm these seem to be the topmost skills an expert controller has to develop.

### 4.3.8 **Inhibiting Factors** slowing down performance.

Many of the controllers reported that load shedding is a great emotional barrier both in the Eskom control room as well as in other control rooms around the world (one person (C14) reported that this was one of the highlights in a recent international gathering of controllers). **Desensitization training in the simulator should become a standard measure to counteract this difficulty.**

**There also seem to be a lot of emotions around the stigma attached to load shedding, and the possible consequences for the controllers, which cause paralysing feelings of anxiety. Management should address this aspect, as a matter of urgency, as this seems to be a "Russian Roulette" phenomenon with dire consequences for all concerned.**

### 4.3.9 **Other Important Factors** which enhance or inhibit performance.

Looking at the findings from the relevant section it appears that the order of importance of other factors that make working in the control room better is as follows:

People/relationships – Knowledge/Experience/Ability –Equipment – Environment – Family – Prospects – Management – Communication - etc.

These are not definitive for everybody as for some "People" come first while for others "Knowledge" etc. However they should all be seriously considered in order to improve working conditions within the control room.

The following factors were identified as not being conducive to optimum performance in the control room, in order of importance:

Management issues – Environment – People – Prospects – Equipment – etc.

From all the above it would be reasonable to surmise that for performance to improve in the control room the inhibiting factors should be removed and the contributing factors should be enhanced. See the recommendations section for more detail.

### 4.3.10 **Value** of this exercise as perceived by the controllers.

All the 14 controllers answered yes to the question, “Was It Useful?” with respect to the whole interview process. To bring awareness of the hidden aspects of performance to the controllers’ minds was a gratifying experience, as when the tacit domain became apparent they all seemed to have a profound experience almost like a lucid dream state (LaBerge 1990). This is consistent with findings, which suggest that when higher brain functions switch on (visual cortex etc.) the brain “lights up” under fMRI scans to reveal a lucid dreaming type experience (LaBerge 1990).

From all the above, we can say that during contingency conditions the controllers’ brains “light up” with various regions being active. Of these the most important as far as expertise goes, as implied by the term **awareness,** is prefrontal lobe activity, which is the key factor in self-awareness and development (performance improvement) as well as resilience (one of the most important anti stress factors (Bridger, 2007). It is also very important in lucid dreaming research (LaBerge 1990) and by extension to this research, as the reporting of the tacit events during the interviews was a sort of a lucid dreaming experience for the controllers. Through activities like this type of interview, the self-awareness of tacit imagery has made it clear to the participants that it is possible to be aware and to directly interact with inner experiences. This can have profound effects on performance, as well as wellbeing within any work environment. The brain does not distinguish between inner and outer information in the way it responds with hormones and other chemistry (LaBerge 1990), which in turn determine physical and mental wellbeing. Therefore becoming aware of and starting to interact directly with tacit imagery, thoughts, etc. is a major step in both improving expertise as well as achieving stress / strain relief at the source. The final chapter, which follows, consists of a discussion, recommendations, and a conclusion.

In the following chapter the implications of these findings will be discussed together with limitations, recommendations, future work, and conclusion.

# Chapter 5

# DISCUSSION, RECOMMENDATIONS and CONCLUSION

This last chapter, presents the discussion, recommendations and a conclusion.
In the discussion we will examine what happened and how it happened, the TRVP analysis, and what could have been done differently and what could be added.
The recommendations section will address the problems within the NCC and what can be done to improve conditions within that environment. This will be done in the light of what was identified in the research, and will be mostly aimed at improving controller performance and the systems and processes, which may affect it.
The conclusion simply serves as an ending to the whole process as well as the possibilities for future research.

## 5.1 Discussion

Here we examine what happened and how it happened, as well as the TRVP analysis, **benefits to theory**, the **limitations of the research**. Also what could have been done differently and what could be added.

### 5.1.1 **The process:** Looking back, lessons learned, the duration, the phases, the results

In hindsight the whole process of initial discussions and invitation by the NCC staff to conduct this research, the structuring of the interview protocols, the actual doing of the simulator exercise, and the interviews that followed, went very smoothly over a period of just over a year. The interviews themselves went very well and the participants were quite keen to contribute once they understood the type of material required from them. The requirement from the researcher (myself) to avoid suggesting anything to the controllers was obviated by the fact that the controllers were very definite about the detail of their descriptions. For instance when asked where exactly a particular image had arisen they

would pin point its mental location within centimetres, by using their hands etc., similarly for descriptions of colours, size, direction of auditory information etc. This qualia richness (Ramachandran 1997) and precision in itself lends credibility to their descriptions as those of true tacit experiences. It should be noted that the interviews were informal with a general structure as mentioned in the chapter on Methods. The interviewer followed the individual controller's style and preference of descriptions, inquiring about the existence of tacit information when the controllers implied its existence by saying or doing something (gesturing), he did not "force descriptions out them". For instance when a controller said that he had no mental images whatsoever, even though he had implied their existence in explicit statements during the interview, the matter was left to rest without further insistence. This is very essential to this type of process, as well as allowing as much time as is required for each controller to become aware and report their inner experience. Even though all the points required were covered, the sequence for each controller was different. This is another important point because in this way each person's individual style of description was accommodated.

The results obtained are quite unique (this research has not been done before anywhere in the world in Power System Control) and comprehensive for this field, but are not unique as far as tacit experience modelling goes (e.g. see Grinder & Bandler, "The Structure of Magic I & II, 1975 and Dilts "Modelling With NLP", 1998.). Overall trends have been observed, and best practice protocols can be formulated allowing for individual preferences as outlined in the Recommendations section. It is hoped that the findings from this research will lead to a paradigm shift about how expertise is structured, the creation of a new vocabulary within the NCC, and within similar environments around the world, and the creation of new areas of training. This is because similar tacit phenomena, like tacit qualia-rich imagery, auditory experiences, and varied tacit/explicit structures, exist in the minds of all control room staff. This is the main contribution of his research.

A secondary contribution is the extension of the RVP process to the TRVP. This is because the tacit domain, which underpins explicit conscious experience, is almost like a

world of its own (Pinker 1999; Anderson 2002). In it, tacit representations simply emerge without the conscious control of the controller (particularly under short time frames), in response to external events, and in turn govern his/her perception of them. To identify these hidden forces and to interact with them directly can have tremendous benefits. This would be analogous to accessing the source code of a computer program and therefore be able to directly alter/optimise its operation. In this context the retrospective descriptions by the controllers of tacit phenomena, the capturing of these, the formulation of best practice protocols and their implementation, all rest on the NLP methods of elicitation used. All this is given theoretical validity by Ramachandran (1997) and the concept of qualia. The presence of qualia information is regarded as one of the main criteria of tacit information elicitation validation. It is therefore quite important to consider the use of all these techniques together to elicit tacit expertise information in this and other fields in which it may be found. In this way great strides can be taken, particularly in the transference of tacit expertise to newcomers in the various fields, as well as for up-skilling and facilitation of transitions when systems change, as was the case with this research.

### 5.1.2 The Results

The results confirm Klein's work and further expand on it by providing the tacit representations, which make RPD possible. **The research as whole was carried out based on well-accepted psychological theory (Pinker 1999, Anderson 2002, Klein 1999, Ramachandran 1997, Ericson & Simon 1993) complimented with innovative NLP techniques (Grinder & Bandler 1975, Bandler & MacDonald 1998), within the confines of the research question.** As set out it was shown that the internal tacit representations in the minds of controllers are what constitutes a major part of their expertise. Various best practice strategies were revealed like zooming out and into particular regions, simplification of mental imagery, continuing to move from mental to HMI imagery thus keeping the attention free, creating enhanced mental depictions of the network which help to navigate contingencies, the existence of strategies to facilitate the transition from old to new HMIs, enhancing existing mental imagery, etc. Overall the

body of knowledge with respect to mental representations has been expanded and a new area of research established. The research provides true, rigorous, repeatable, data collection and interpretation techniques, which should reveal similar results in similar environments. This does not imply that in all control rooms the same issues prevail but it can be said that tacit representations are at the core of tacit expertise in all such environments.

### 5.1.3 Difficulties Encountered

Some of the difficulties encountered were:

Some minor time constraints with respect to accessing the controllers over the period of the year, as they were involved with many activities related to the FIFA football World Cup which made scheduling quite a challenge.

Another difficulty was the unpredictability of the participants' state as they came in for the sessions. However they all participated fully as mentioned above.

It would have been better to have more than one session with some of the controllers, although it was already quite time consuming, particularly with those who had difficulties in stabilising the network. This can be addressed later on, as interventions for performance enhancement are put in place.

Their emotional states were reported on by self-reports after the experience. This is open to primacy and recency effects. It would have been better to get more reliable/biological measures of the correlation of their state on a regular basis. However what was elicited is sufficient for the purposes of this research, the main focus of which were the tacit content and structure of the controllers' experiences in response to the TEMSE displays. On the other hand the realistic style of performing the simulator exercise without any prior preparation resulted in a real-life, emotionally charged, experience.

The fact that only half of the NCC staff were included in this study does not impact much on the results (Nielsen, 1994), however it would have been useful, for the controllers themselves, to have all of them participate. This can also be addressed at a future date. At this stage all the participants were volunteers and so for ethical reasons the number of participants was limited. It might also be possible in the future to train NCC staff in NLP techniques, so that experts in elicitation can be created within the NCC environment.

### 5.1.4 What Could Have Been Better?

Other than to address the issues in the section above, and given the prevailing circumstances, the work was carried out quite satisfactorily and at this stage there is not much that could have been done better as the researcher being an external to the NCC person allowed for a free and uninhibited interaction.

### 5.1.5 Future Work

It would be useful to extend this investigation to normal operating conditions, operating error conditions, and other Eskom control rooms. There is also a strong possibility to introduce neuro/bio-feedback equipment, as part of the simulator training, in order to monitor the state of each controller as they do their work. This will be in order to provide training in state management for those who want it at first, with the help of such equipment, and later on as another aspect of control room best practice up-skilling. Later on, eye-tracking equipment may also be included in order to assess visual momentum and fixation, as a further attempt to improve performance. Also the area of stress management is a domain where tacit forces wreak havoc, and this too can be investigated. All these types of investigation can be extended to all Eskom control rooms in generation, distribution, and other control rooms such as Telkom, air-traffic, etc. Considerable interest has been shown from counterparts in the USA as well, where the results of this and related research have been presented over the last three years (see EPRI Switching Safety and Reliability conferences from 2009 to 2011). Another dimension that can be investigated is the relationship between individual controller scientific understanding of

the basic theoretical concepts of network behaviour during emergency conditions and the level and complexity of their visualisation.

### 5.1.6 The Limitations of this Research

The main content of this research must be seen as primarily a contribution to control room expertise enhancement practices and not as a contribution to psychology theory. It is the innovative combination of existing methodologies, which made this possible. The section on the TRVP is a secondary contribution, which can be considered as such in the field of cognitive and engineering psychology where elicitation of tacit information is not part of current practice. The current material of elicitation of RVPs does not include the tacit domain, as defined in the Background section. This research then falls within a very specific narrow band and a very specific context; that is the domain of the Eskom NCC and other similar control rooms where controllers' tacit mental content and structures are the main distinguishing factor between novices and experts. Also it is important to note that what was investigated was what happens in minds of controllers under contingency conditions. What happens in their minds under normal operations was not investigated at this stage. Also what was not investigated was what happens in the minds of controllers who perform operating errors. This may form the topic of further studies. The findings from this research can then be used as a springboard for research in other similar environments, as the techniques used in this particular study, and in this particular context, have shown promising results. The tacit domain, as defined earlier, is an area of investigation, which has not been considered in control room environments, to this extent this work can open up the field for further research in any control room environment, even though the results here pertain to the Eskom NCC only. Another limitation was that the individual controller level of scientific understanding of the basic theoretical concepts of network behaviour during emergency conditions was only partially addressed. This aspect was only partially considered in the section on individual controller qualifications and experience in power system control room work.

## 5.2 Recommendations

As mentioned in the Introduction, this research was commissioned by Eskom in order to shed some light on the tacit processes, which are at the core of the type of expertise required for control room staff and their relationship with the TEMSE system. The findings of this research have achieved this to a considerable extent. Together with the main findings, stemming from the research question regarding tacit content, processes, and emotions, a number of other related issues were elicited during the interviews as discussed in the Other Important Factors section. As a result of all the above, from all the statements made by the controllers, and the findings of this research the following recommendations have been put forth for Eskom, under three categories:

- Controller performance enhancement
- HMI design
- Management related Issues

### 5.2.1 Controller Performance Enhancement

1. As NLP techniques were used to elicit the material for this research, it would be useful to create **NLP training** opportunities for NCC staff, like the controllers, training and shift managers, etc. They would benefit greatly from such training as the NLP communication skills used to conduct the research can be used to enhance expertise in the control room itself, as well as to allow controllers to interrogate operators in the field for accurate feedback when they perform operations. The NLP communication skills would open up a whole new world of information which can be elicited between controllers and/or field staff, which would reveal further hidden best practice strategies, for all to share. In other words at this stage the only training that takes place at the NCC is technical in nature, it could therefore be useful to include other aspects, such as NLP training, to enhance mental competence skills. This would assist the experienced controllers to move further, it would open up mentoring opportunities, assist newcomers to get to high levels of expertise sooner, provide tools to acuire accurate feedback from field staff, and also

capture the hidden expertise structures in the minds of experienced controllers for others to benefit from. This last item is of critical importance at the NCC, as many older controllers are set to retire and take their tacit skills with them.

2. This research has opened up a whole new realm of investigation, which has to do with the core of tacit skills that are the foundation of expertise. The methods applied can be used in any control room to reveal the underlying forces that can have so many benefits, as discussed above. It is therefore recommended that the same work be carried out in **all Eskom control rooms** in order to make the benefits of this work available in all Eskom environments. This would be particularly so for Koeberg Power Station, which is another national key point.

3. This research was carried out under contingency conditions. A further investigation can expand our knowledge as to what goes on in the minds of controllers under **normal operating conditions**. The findings of such an investigation would be far more suited for training of new staff, as they would start their exposure to the NCC with the presumably simpler aspects of their work.

4. Another area where this work could be of use would be in the **investigation of control error investigation**. At present there is no awareness as to what happens in the minds of controllers who perform operating errors. This knowledge would be of great benefit in learning from mistakes and sharing that information. Training in the simulator and other methods could be used to create new neural pathways in the brains of controllers in order to improve performance.

5. The information about how long it took to make the transition highlights the need for investigations such as this. Suitable **interventions tailored for each individual** could make the transition process smoother and easier. As a result best practice protocols can be formulated and introduced to all, particularly newcomers.

6. As some controllers (57% (8 / 14), who could be used as references, took shorter times to make the transition, it would be interesting **to find out what made the transition easier** for them. In this way we can expand our knowledge of mental adaptations in control room environments and identify best practice strategies in this regard which can be passed on to those who have not made the transition yet or in other similar environments.

7. Further the 14% (2 / 14) who reported they have their own mental images, which are neither TEMSE nor ENCOR could be used to further investigate their expertise levels and perhaps develop **alternative best practice strategies** to further enhance performance.

8. The participants who did not make any reference to self (wrote only about what happened) in their written accounts and gave very little information during the interviews, are a minority in the group. These could perhaps be good **candidates for further training,** in order to validate the adaptations discovered from those who made the transition quickly.

**9. The cognitive sequences mentioned** are not related to the HMI displays per se. However it is important to note them, as they can be relevant to best practice protocols. These sequences which included looking at the screens, paying attention to mental imagery, experiencing intense emotions and other aspects of experience could be included as part of **future simulator training**.

10. The quality of the **tacit images and ease of their manipulation** seem to be some of the key signs of high levels of expertise, as those who displayed such abilities managed to deal with the contingencies well. This fact can now be factored in when designing **training** and other interventions for performance enhancement. Further, the vocabulary used to describe these tacit images and structures, should become part of the everyday discussions in the control room in order to help controllers to expand their skills and learn

from each other's inner experiences, which are what makes them stand out from other system engineers.

11. Two of the controllers were asked after the interview, "What would happen if you would zoom out and see the whole network first, then decide what needs doing?" In both cases they reported that their skill level would be much higher and that they would have had better alternatives from the start. In order for a controller to do this, they need to have a good mental image of the network, as well as to develop the ability to **remain calm under contingency conditions** so that they have the cognitive space to mentally zoom out in order to decide what to do. This mental dexterity seems to be part of the "best practice" strategies used by the most competent controllers as mentioned above. Together with emotional calm they seem to be the topmost skills a top controller has to develop. **Training in the simulator** and elsewhere could make these skills available to all.

12. Based on the findings of this research **selection criteria** for new controllers can be created in order to recruit the best possible staff for the NCC out of all the various applicants.

13. Many of the controllers reported that **load shedding** is a great emotional barrier both in the Eskom control room as well as in other control rooms around the world (one controller reported that this was one of the highlights in a recent international gathering of controllers). **Desensitization training** in the simulator could become a standard measure to counteract this difficulty, particularly as the network is becoming more complex and more vulnerable, with a variety of new measures being introduced like smart grids, independent power suppliers, etc.

14. The verbal **thought processes** which flood a controller's awareness both inhibit his work and, I would suspect, create long term stress / strain problems. This last possibility could be monitored and its long-term implications assessed as a matter of urgency, as stress problems are quite common in the control room.

**15. Human relations** in the NCC are a key performance-enhancing factor, their improvement, where required, should be made a top priority. This can be achieved by **complete shifts working together in the simulator** room in order to observe (on video) technical as well as interpersonal dynamics, and then apply remedies before contingencies take place. Such simulator training would address the knowledge expertise requirement as well as making it possible for teams to become more streamlined when working under adverse conditions. This type of approach is termed Crew Resource Management (CRM) and is used to train flight crews of commercial aircraft with great success.

16. The investigation of mental activities, like this style of interviewing, self-awareness of tacit imagery etc. has made it clear to the participants that **it is possible to be aware of and to directly interact with inner experiences**. This can have profound effects on performance, as well as wellbeing within any work environment. It is well known that the brain does not distinguish between inner and outer information (LaBerge 1990) in the way it responds with hormones and other chemistry, which in turn determine physical and mental wellbeing. As discussions about tacit factors are absent within the control room environment this should become an area of training, as it can have great benefits to expertise levels.

**17. A Gap Analysis** could be carried out for each controller to find out how they fare with respect to the list below, as the NCC is a national key point worthy of critical people care:

Technical expertise
Interpersonal skills
Tacit / cognitive abilities/ skills
Emotional skills
Career prospects
Family relations
Financial standing vs. aspiration

Health issues
Spiritual issues
Representation and information dissemination
Pension readiness
Performance
Team dynamics
Ergonomics needs
Further studies
Promotion prospects
Retention policies

For these the available collective wisdom of all concerned, and “deep democracy” processes, which allow the wisdom of dissenting views to be included, may be used as well.

All of the above should go a long way in improving:

- **The controllers’ abilities,** by bringing to the surface of conscious awareness their individual subconscious processes;
- **Identify the type of cognitive, simulator, and other training** required to improve the situation for each individual controller, so that the mental adaptations required to use the TEMSE network computer-interface equipment can be facilitated;
- **Assist newcomers working on the new equipment** by learning from those controllers who had mental images and high expertise strategies formed years ago;
- **Identify tacit “best practice” characteristics** in order to improve the Naturalistic Decision Making abilities of all the controllers by creating suitable training protocols for Power System Controllers around the world.

### 5.2.2 HMI Design

**1. The slowness of the TEMSE system** should be cause for some concern as information about best practice in this regard has been available for some time as mentioned in the EPRI report of 1982. The same applies for voltage level colours. These matters are for the system developers to address. The rest of the 1982 EPRI report recommendations should also be scrutinised and compared with the TEMSE system so that measures can be implemented to improve its performance.

2. As far as **further computer display design** goes, it is suggested that during contingencies the controllers could be presented with a simplified network diagram of the network, superimposed on the geographical map of the country, on a separate monitor screen, with indications of the affected equipment and also of any equipment that can make a difference. This would be a physical depiction of what the top experts do in their minds. I.e. if there are low voltages, capacitor banks relative to the affected area can be shown, load shedding options prioritised etc. If voltages are high, the location of SVCs, reactors, etc. can be shown to bring voltage levels down. This type of HMI display, also known as decision support or expert system, can be used to train the controllers, particularly the newcomers, in the simulator and to navigate contingencies in the control room. Another aspect of HMI design enhancement would be to produce a screen, which can be used to train controllers to zoom-out and zoom-in on various sections of the network, during simulator training. Similarly for the case of own mental models which are different from TEMSE images, HMI equivalents could be created to train newcomers in alternative information processing strategies. **These type of developments can be patented and the writer reserves all the rights due to him.**

### 5.2.3 Management Related Issues

1. One of the controllers initially got stuck and could not continue with the work as contingencies kept on getting worse. The same person however, after the exercise during the interview, was able to change his state to such an extent that he was able to find alternatives and sort out the situation without any difficulty at all. This was because it was put to him, “What would you do if there was no threat of reprimand if things got out of hand?” Suddenly his mind came to life and he was able to provide solutions to all the contingencies of the exercise. The sequence of his work before and after is captured in the relevant results section. Looking at the two sequences, the main difference is the great deal of internal verbal processing (the tonality and other sub-modalities are very important here) going on in his mind together with powerful emotions relating to penalisation. Given this example, one wonders how prevalent this phenomenon is, as similar (but not as intense) reports were provided by a few other controllers, off the record. Also, given the dramatic come back of the controller above, I wonder what possibilities for performance enhancement, **reviewing the existing regulations regarding penalization** could create. Many controllers mentioned that discussions and other information and training interventions could become part of error management particularly with respect to the tacit aspects of an incident. Also the introduction of neuro/bio-feedback training may help in this respect. Then, as far as fatigue related incidents go, fatigue monitors and person-to-person feedback regarding state management and attitude could be introduced in the control room.

2. There also seem to be a lot of emotions around **the stigma attached to load shedding,** and the possible consequences for the controllers, which cause paralysing feelings of anxiety. Management could address this aspect, as a matter of urgency, as this is a “Russian Roulette” phenomenon with dire consequences for all concerned.

3. Measures could be taken to address the management practices and processes **identified as performance inhibiting factors**, **remove the environmental inhibiting factors** (such as lighting and the absence of windows etc.) and **create a career path,** which allows progression beyond the confines of the control room for the controllers. Together with

these all the other minor factors should receive due attention as they may effect individuals and so they should be treated as such (such as transition to pension etc.).

4. Based on comments made by the controllers, **regular (weekly / monthly) meetings with all staff** could be made standard in order to discuss and diffuse potential emotionally charged issues and for the sake of motivation and morale building, such as interests, management issues, processes, representation on decision making bodies, age group issues, etc.

5. Another aspect that was mentioned was **mentoring**. Suitable controllers can be identified to mentor newcomers to the NCC on a part time basis, particularly those transitioning to retirement.

6. A distinction could be made between the technical authority of the shift manager and aspects relating to issues about **relationships among the shift members.** In this respect a suitable person could be elected within the shift, to have the final say regarding relationship issues. In this regard each person's strengths could be identified and suitable responsibilities given to him or her to deal with personal relationship and other emotionally charged issues.

7. A number of other issues, like **360 degree feedback, status and bonus criteria, rigor in assessing levels of competence for promotion, responsibility for contingencies** (from the individual to the whole of the shift), **two way management-staff communication, on going qualifications improvement, collaborations with universities, professional registration, breaking the us-and-them barriers, preparation for pension, part time work for retired controllers** who could act as mentors, etc. could play a role in improving conditions within the NCC.

8. Other suggestions made included the following: introduction of periods of training outside the control room, bring **family members in the NCC** to meet all shift members, the **sharing of personal stories**, histories, and aspirations in order to improve relations.

All of the above recommendations stem from the findings of this research. Some come from the main questions addressed and others from the secondary issues around controller performance enhancement. They should be regarded or treated as processes not as once off interventions. The final aim should be to create an open ended environment or culture in which controllers can thrive, by being introduced to and progress in their career at the NCC, in a practical hands-on way. This can include **overt technical as well as tacit/cognitive training**, in order to move up to higher positions as per individual aspirations and with the full support of all concerned. There should also be **enough redundancy** built into the controller numbers, so that if a few are transferred to other sections there isn't a vacuum left behind.

## 5.3 Conclusion

In the research hypothesis it was stated, "there are tacit mental structures, content, and emotions, which arise within the minds of the controllers at the NCC, as they work with the newly implemented Windows based TEMSE computer interface, and it these tacit structures and content which determine the controllers' response to HMI information when decision time frames are short."

All the three aspects (tacit content, structures and emotions) in the hypothesis have been addressed in the findings section. It has been shown that the tacit phenomena responsible for shaping the controllers perceptions of their world, which have until now remained subconscious phenomena, have now been brought to light. By conducting this research this new world of investigation has now been made available for further study and the hypothesis has been shown to be correct. By becoming aware of this new world, a variety of possibilities for improvement have been put forth in the recommendations section. This is of critical importance in todays world of Power System Control.

Over and above these, a number of associated factors have been identified which play a key role in the emergence, type, and intensity of tacit phenomena and emotions. The

results have been discussed and consolidated in group fashion, however each individual should be considered on their own merit and interventions, as recommended above, need to be tailored to individual needs. This research has opened up a whole new area of investigation and expertise enhancement for Eskom and control room staff around the world. This was done by bringing to the surface of awareness factors, which have bedevilled control room staff for years, revealing some of the significant hidden forces behind expertise.

It is hoped that this research will lead to further investigations, joint activities and collaboration in the NCC and other Eskom control rooms, particularly making use of neuro and biofeedback. It is also hoped that the findings above will play a role in shaping the design of computer display content and structure in the future, in South Africa and abroad. In this way we have come a bit closer to "discovering the form of mental representations (the symbol inscriptions used by the mind) and the processes (the "demons") that access them" (Pinker 1999) in the NCC control room. By pinning down individual mental representations we can continue to strive to improve individual's performance in the Eskom NCC and by expanding the methods of elicitation we can move closer to identifying the true mental representations on an individual basis, with rigor. **The contribution of this research has been to reveal the hitherto invisible tacit/subconscious domain of the NCC controllers' minds. By doing so the skill base and work performance of any control room staff can be improved in the real world of Power System Control in ways that were not possible before. This is because mental training skills can be added to the technical simulator training, taking place at present. Design of HMIs can be improved as well, as with this information HMIs can be optimised to suit controllers' needs. Also, the extension of the current RVP to the TRVP analysis elicitation methodology is a significant secondary contribution, as its application can open the field of research in any suitable environment, anywhere in the world, where humans interface with machines and tacit forces are at play in short time frames.**

# REFERENCES

**Anderson J. R. "Cognitive Psychology and its Implications",** 4th Ed. W H Freeman & Co., 2002.

**Arend U. "Analysing Complex Tasks with an Extended GOMS* Model",** Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Bainbrdge L. "Analysis of Verbal Protocols from a Process Control Task. Mental models and Human-Computer Interaction 1",** Elsevier Science Publishers B.V. (north Holland), 1990.

**Bainbridge L "Comlex Cognition" Papers by L Bainbridge, http://www.bainbrdg.demon.co.uk , 1998.**

**Bainbridge L "Types of Representation, Different representations, and the implications for cognitive processing"** book, 1988, http://www.bainbrdg.demon.co.uk/Papers/TypesRep.html.

**Bainbridge L. "Cognitive Processes in Complex Tasks: Introduction and Discussion",** Ergonomics 1993, Vol. 36, No 11, 1273-1279.

**Bainbridge L., Beishon R.J., Hemming J.H., Splaine M. "A Study of Real-time Human Decision-making using a Plant Simulator**", Operational Research Quarterly, Special Conference Issue 1968, 19 91-106 reprinted in Edwards &;Lees, pp.91-104.

**Bandler R. "Magic in Action"** book, Meta Publications, 1992.

**Bodenhamer B. G., Hall L. M. "The Users Manual for the Brain Vol. I & II"** book, Crown House Publishing, 2002.

**Bandler R., Macdonald W. "An Insiders Guide to Sub-Modalities"** book, Meta Publications, 1988.

**Bartlett, F.C. "Remembering: An Experimental and Social Study."** Cambridge: Cambridge University Press, 1932.

**Baxter G. D. and Ritter F. E., "The rising Importance of Cognitive Engineering",** Review **of Sarter N. B. Amalberti R., "Cognitive Engineering in the Aviation Domain"** Mahwah, NJ: Erlbaum, 2000.

**Becerra-Fernandez, I. and Sabherwal, R. "Knowledge Management: Systems and Processes."** Armonk (N.Y.), London : M.E. Sharpe, 2010.

**Bridger R S "Occupational Stress Research in the Naval Service: Past Present and Future"** Report, Human Factors Department Institute of Naval Medicine, UK, 2007.

**Bruner J S Goodnow JJ, Austin GA "A Study of Thinking",** book, John Willey and Sons, 2009.

**Candy R.,** Eskom HMI designer, personal communication, 2011.

**Christie R.D.,** Mahadev P.M. "**EPRI Report "Visualizing Power System Data",** EPRI TR-102984, Project 8010-25, Final report, 1994.

**Decortis F. "Operator strategies in a Dynamic Environment in Relation to an Operator Model**", Taylor and Francis Ltd. 1993, 0014-0139/93. Institute for Engineering and Informatics Italy.

**Dilts R. "Modelling With NLP"**, book, Meta Publications, 1998.

**Dilts R., Grinder J., Bandler R., De Lozier J. "Neuro-Linguistic Programming (The Study of the Structure of Subjective Experience)" Vol. I.** Meta Publications, 1980.

**Dy-Liacco T.E. "Control Centres Are Here To Stay"**, IEEE Computer Applications in Power 2002. ISSN0895-0156/02/2002IEEE.

**(ELCON) Electric Power Components and Systems "The Economic Impacts of the August 2003 Blackout"** Volume 30, Issue 8, 2002, Pages 877 – 888. Electricity Consumers Resource Council, February 9, 2004.

**EPRI "Interconnected Power System Dynamics Tutorial",** Second Ed., EPRI TR 107726, 1915-16, Final Report, March 1997.

**Ericson K A, Simon H A, "Protocol Analysis: Verbal Reports as Data"** Book, MIT Press, 1993.

**Fischer G. "The Importance of Models In Making Complex Systems Comprehensible**", Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Fisher J. Newcombe P. "Identifying Operators' Representations of Complex Systems Through Cluster Analysis**", Ergonomics SA, 1990, (2(2), 86-95).

**Frank J. C.** "**Human Factors Review of Electric Power Dispatch Control Centres",** Volume 4: Operator Information Needs. **EPRI** El-1960 Volume 4 Project 1854-1 Final Report October 1982.

**Goodstein, L.P., Anderson, H.B. and Olsen, S.E. (eds.) "Tasks, Errors and Mental Models." Taylor and Francis Ltd., London, pp. 70-91, 1993.**

**Gopher D Koriat A, "Cognitive regulation of Performance: Interaction of theory and application",** 2012 American Psychological Association **http://psycnet.apa.org/psycinfo/1999-02468-000**

**Grinder J. Bandler R. The structure of Magic I**. Science and Behaviour Books Inc. 1975, p39-56.

**Grinder J. Bandler R. The structure of Magic II**. Science and Behaviour Books Inc. 1975, p3-26.

**Guttromson R.T., Greitzer F.L., Paget M.L., Schur A., "Human Factors for Situation Assessment in Power Grid Operations",** Report, August 2007, U.S. Department of Energy, Contract DE-AC05-76RL01830, PNNL-16780.

**Hanisch K.A. "Cognitive Representations, Control, and Understanding of Complex Systems**: A Field Study Focussing on Components of Users' Mental models and Expert / Novice Differences", Ergonomics, 1991, vol.34, No 8, 1129-1145.

**Hockey G. R. J., Briner R. B., Tattersall A. J. "Assessing the Impact of Computer Workload on Operator stress: The Role of System Controllability", Ergonomics**, 1989, vol. 32, No. 11, 1401-1418.

**Hofmayer J** Eskom NCC Training officer, personal communication, 2010.

**Johnson Laird P N, "Mental models and deduction"** 2001, Trends in Cognitive Sciences Vol.5 No.10 October 2001.

**Kellogg R.T. "When Can We Introspect Accurately About Mental Models",** Memory and Cognition 1982 Vol. 10 (2), 141-144.

**Khalid H.M., "Embracing Diversity in User Needs for Affective Design"** Applied Ergonomics 37, 2006, P.409–418.

**Klein G. "Sources of Power: How People Make Decisions", book,** MIT Press, 1999.

**Knothe P. H. (ESKOM Power Station Engineering Division) "The Man Machine Interface in Electrical Generating Plant Control – The Ergonomic Design of Majuba Power Station Unit Control Room",** EID symposium, 1989.

**Korzybski A. "Manhood of Humanity" 2nd Ed.,** Institute of General Semantics, 2001.

**Korzybski A. "Science and Sanity" 5th Ed**., Institute of General Semantics, 2000.

**LaBerge S., "Lucid Dreaming", Sounds True, 2004.**

**Lazanas P., "Investigating the way National Grid Controllers Visualize the Electricity Transmission Grid using a Neuro-Linguistic Programming (NLP) approach.",** Conference Proceedings HCI International 2007, Beijing, China.
**Lazanas P "Techniques for the Elicitation of Subconscious (Tacit) Expertise Strategies and Visualization"** Workshop, EPRI 14th Annual Power Switching Safety & Reliability Conference, San Diego, USA, 2010.

**Libet B "Mind Time: The Temporal Factor in Consciousness"** Book, Harvard Uni. Press, 2005.

**Mahadev P. M., Christie R. D. "Minimizing User Interaction in Energy Management Systems: Task Adaptive Visualization",** IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996.

**Mahadev P.M**., Christie R.D. "**Envisioning Power System Data: Concepts and a Prototype System State Representation**", IEEE Transactions on Power Systems Vol 8, No 3, August 1992. 0885-8950/93/1992 IEEE.

**Mahadev P.M., Christie R.D.,** "**Envisioning Power System Data: Vulnerability and Severity Representations for Static Security Assessment**", IEEE Transactions on Power Systems Vol 9, No 4 November 1994, 0885-8950/94/1994 IEEE.

**Mcleod S., "Unconscious Mind" 2009,**
**http://www.simplypsychology.org/unconscious-mind.html**

**Miller G A, "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information",** 1956, Harvard University, Psychological Review, 63, 81-97.

**Mitsche J.V.** "**Stretching the Limits of Power System Analysis**", IEEE Computer Applications in Power 1993. Issn 0895-0156/93/$3.00ã1993 IEEE.

**Mitsui H., Christie R. D. " Visualizing Voltage Profiles for Large Scale Power Systems",** IEEE Computer Applications in Power, ISSN 0895-0156/97, 1997.

**Muller J.,** Eskom NCC training manager, personal communication, 2010.

**Murray D. "Modelling for Adaptivity. Mental models and Human-Computer Interaction 1",** Elsevier Science Publishers B.V. (north Holland), 1990.

**Nielsen, J. "Estimating the Number of Subjects Needed for a Thinking Aloud Test."** International Journal of Human-Computer Studies, 1994, Vol. 41. N. 3. 385-397.

**Nigel J.T., "Mental Imagery",** The Stanford Encyclopaedia of Philosophy (Fall 2010 Edition), Edward N. Zalta (ed.), URL <http://plato.stanford.edu/archives/fall2010/entries/mental-imagery/>.

**O'Connor J. "NLP Workbook"** book, Element, 2002.

**O'Connor J., Seymour J. " Introducing NLP"** book, Aquarian, 1993.

**Overbye T, J., Yan Sun, Wiegmann D. A., Rich A. M., "Human Factors Aspects of Power System Visualizations: An Empirical Investigation**" IEEE Transactions on Power Systems , 2003.

**Overbye T. J. "Human Factors Aspects of Power System Visualizations",** PSERC Univ. of Illinois, May 2, 2002.

**Overbye T.J.** "**New Techniques for Power System Visualization Under Deregulation**", 2000, IEEE 0-7803-5935-6/00/2000IEEE.

**Overbye T.J. "Visualization of Power Systems"**, Final report. PSERC Publication 02-36, Nov 2002.

**Overbye T.J., Weber J.D.** "**New Methods for the visualization of power System Information**", IEEE Computer Society, 2000, 0-7695-0804-9/2000 IEEE.

**Overbye T.J., Weber J.D.** "**Visualization of Power System Data**", Proceedings of the 33rd Hawaii International Conference on System Sciences, 2000, 0-7695-0493-0/00/2000IEEE.

**Overbye, T.J., "Visualization Enhancements for Power System Situational Assessment"** Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, IEEE Issue Date: 20-24 July 2008 On page(s):1-4

**Perls F., Hefferline, Goodman, "Gestalt Therapy"** book, Penguin, 1976.

**Petroianu A. "Power System Operation Fundamentals"**, short course outline, University of Cape Town, 2003.

**Pinker S. "How the Mind Works**", book, Penguin books, 1999.

**Ramachandran V.S., Hirstein W., "Three Laws of Qualia: What Neurology Tells Us about the Biological Functions of Consciousness, Qualia and the Self"** Journal of Consciousness Studies, 1997, 4, No. 5-6, pp. 429–58.

**Rasmussen J. "Mental Models and the Control of Action in Complex Environments. Mental models and Human-Computer Interaction 1"**, Elsevier Science Publishers B.V. (north Holland), 1990.

**Rasmussen, J. and Jensen, A, "Mental procedures in real life tasks: a case study of electronic trouble shooting."** Ergonomics, 17, 293-307, 1974.

**Rasmussen, J., "On the Structure of Knowledge - a Morphology of Mental Models in a Man-Machine System Context",** Riso Report Riso-M-2192 (Roskilde. Denmark : Riso National Laboratory), 1979.

**Rasmussen, J., "Models of mental strategies in process plant diagnosis. In Human Detection and Diagnosis of System Failures",** edited by J. Rasmussen and W.B. Rouse (New York: Plenum Press), 1981.

**Robert G. Hockey J. "Styles, Skills and Strategies: Cognitive Variability and its implications for the role of Mental Models in HCI**", Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Sasse M. "How to T(r)ap User's Mental Models",** Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Senge P. M. "The Fifth Discipline"** Currency Doubleday, 1994.

**Senge P. M, Kleiner A, Roberts C, Ross R. B, Smith B. J. "The Fifth Discipline Field book" book,** Nicholas Brealey, 2003.

**Shalif I. "Focussing on the Emotions of Daily Life A Guide for Their Maintenance". www.netvision.net.il/php/gsshalif> ,** May 2004.

**Shalif I. "The Emotions and the Dimensions of Discrimination Among Them in Daily Life"**. A study towards a Ph.D. dissertation, Bar-Ilan University, 1987.

**Siegel D. J. W. W. , "The Mindful Brain: Reflection And Attunement In The Cultivation Of Well-Being."** Norton & Company, New York, USA, 2007.

**Stagg G.W**., **Abibi M., Laughton M., Van Ness J.E., Wood A.J.** "**Thirty Years of Power Computer Applications. IEEE Computer Applications in Power**", 1994, ISSN 0895-0156/94/1994IEEE.

**Thatcher A.J. "A Cognitive Task Analysis in a Complex Process Control Environment**", MSc dissertation University of the Witwatersrand, Johannesburg 1995.

**Visser W. Morais A. "Concurrent Use of Different Expertise Elicitation Methods Applied to the Study of the Programming Activity",** Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Wickens C D, Hollands J G "Enginnering Psychology and Human Performance"** Book, 3rd Ed., Prentice Hall, 2000.

**Wickens, C. D. "Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation Awareness Theory and Measurement"** 2008, University of Illinois, Champaign, Illinois.

**Wiegmann, D.A., Essenberg, G.R., Overbye, T.J., Sun, Y., "Human Factor Aspects of Power System Flow Animation"** IEEE Transactions on Power Systems Issue Date: Aug. 2005 Volume: 20 Issue:3 page(s): 1233 – 1240

**Wiegmann, D.A., Overbye, T.J., Hoppe, S.M., Essenberg, G.R., Yan Sun, "Human Factors Aspects of Three-dimensional Visualization of Power System Information" Power Engineering Society General Meeting, 2006. IEEE Issue Date: 0-0 0, Page: 7.**

**Wilson J.R. Rutherford A. "Mental Models: Theory and Application in Human Factors",** Human Factors, 1989, (31(6), 617-634).

**Zsambok C. E., Klein G. "Naturalistic Decision Making",** Lawrence Erlbaum Associates, 1997.

# BIBLIOGRAPHY

**Acerman D., Tauber M. I. "Mental Models and Human Computer Interaction 1 & 2",** Elsevier Science Publishers, 1990.

**Bandler R., Grinder J. "Patterns of Hypnotic Techniques of Milton Erickson M. D.Vol. I"** book, Meta Publications, 1975.

**Bateson G. "Mind and Nature a Necessary Unity"** book, Hampton Press, 2002.

**Bateson G. "Steps to an Ecology of Mind"** book, University of Chicago Press, 2000.

**Beck D. E., Cowan C. C. "Spiral Dynamics"** book, Blackwell, 1996.

**Belkin N.J. Brooks H.M. Knowledge Elicitation Using Discourse Analysis**. Int. J. Man-Machine Studies, (27, 127-144) 1987.

**Biehal G. Chakravarti D. "The Effects of Concurrent Verbalization on Choice Processing"**, Journal of Marketing Research Vol. XXVI, Feb. 1989, 84-96.

**Borgman C. L., "The User's Mental Model of an Information Retrieval System: An experiment on a Prototype Online Catalogue",** Int. J. Man-Machine Studies, 24, 47-64, Academic Press Inc. 1986.

**Bower G.H. Morrow D.G. "Mental Models in Narrative Comprehension",** Science, Vol. 247, p44-48, 1987.

**Brenner C. "An Elementary Textbook of Psychoanalysis"** Anchor Books, 1974.

**Brezillon P., Pomerol J.C., "Joint Cognitive Systems, Cooperative Systems And Decision Support Systems: A Cooperation In Context"** Proceedings of the European Conference on Cognitive Science, Manchester, UK, April 1997, pp. 129-139.

**Carroll J.M. Mack R.L. "Metaphor, Computing Systems, and Active Learning**", Int. J. Man-Machine Studies, 1985, (22, 39-57).

**Corydon D. "Handbook of Hypnotic Suggestions and Metaphors" 1st Ed.**, Norton, 1990.

**Csikszentmihalyi M. "Flow: The Psychology of optimal Experience",** Harper Perennial, 1991.

**Dilts R. "Sleight of Mouth Techniques"** book, Meta Publications, 1999.

**Farooq M.U. Dominick W.D. "A Survey of Formal Tools and Models for Developing User Interfaces",** Int. J. Man-Machine Studies, 1988, (29, 476-496).

**Flood R. L. "Rethinking the Fifth Discipline",** Routledge, 2002.

**Flood R. L., Jackson M. C. "Creative Problem Solving"** John Wiley & Sons, 1993.

**Glenberg A.M. Langston W.E. "Comprehension of Illustrated Text: Pictures Help to Build Mental Models",** Journal of Memory and Language, 1992, (31, 129-151).

**Grinder J., De Lozier J., Bandler R. Patterns of Hypnotic Techniques of Milton Erickson M.D. Vol. II"** Meta Publications, 1977.

**Hall L. M. "Meta States"** Neuro Semantics Publications, 2000.

**Hall L. M. "The Matrix Model"** Neuro Semantics Publications, 2003.

**Howard P. J. "The Owners Manual for the Brain"** Lernian Press, 1995.

**Jung C. G. "Memories Dreams Reflections"** book, Collins, 1977.

**Jagacinski R. J. "Describing the Human Operator's Internal Model of a Dynamic System**", Human Factors, 1978, (20(4), 425-433).

**Laws J.V. "Video Analysis in Cognitive Ergonomics: A Methodological Perspective",** Ergonomics, 1989, Vol. 32, No 11, 1303-1318.

**Lindgaard G., Whitfield T.W.A., "Integrating Aesthetics Within an Evolutionary and Psychological Framework"** Theoretical Issues in Ergonomics Science, 2004, vol. 5, no. 1, P 73–90.

**Meyer W. F., Moore C., Viljoen H. G. "Personology (From Individual to Ecosystem)"** Heineman, 1997.

**Rutherford A. Wilson R. "Models of Mental Models: An Ergonomist – Psychologist Dialogue**", Mental models and Human-Computer Interaction 1, Elsevier Science Publishers B.V. (north Holland), 1990.

**Staggers N. "Mental Models: Concepts for Human-Computer Interaction research",** International Journal for Man-Machine Studies, 1993, (38, 587-605).

**Weinberg I. "Quantum Leap"** book, Sigma Books, 1998.

# APPENDIX A

Below are shown the written descriptions of what happened before the interviews, and the sketches produced by the controllers:

**C1**

Eskom. C1 28/11/10.

1 & 2 400kV LINES TRIPPED.
CHECKED OUT ALARMS - UNABLE TO CLOSE - IE. L/O.
- LOW VOLTAGES
- WITKOP LOAD SHED SCHEME OPERATED.
- NO OVERLOADING OF OTHER LINES.
- PELLY VOLTAGES LOW.
- WARMBAD VOLTAGES LOW.
- ESSELEN REASONABLY LOW.




PRESUMABLY VELD FIRES CAUSED TRIP DUE TO TIME OF EVENT.
OPENED LOAD BREAKERS AT WARMBAD TO STABILISE VOLTAGES.
SAME AT PELLY.
VOLTAGES SETTLED AT REASONABLE VALUES.

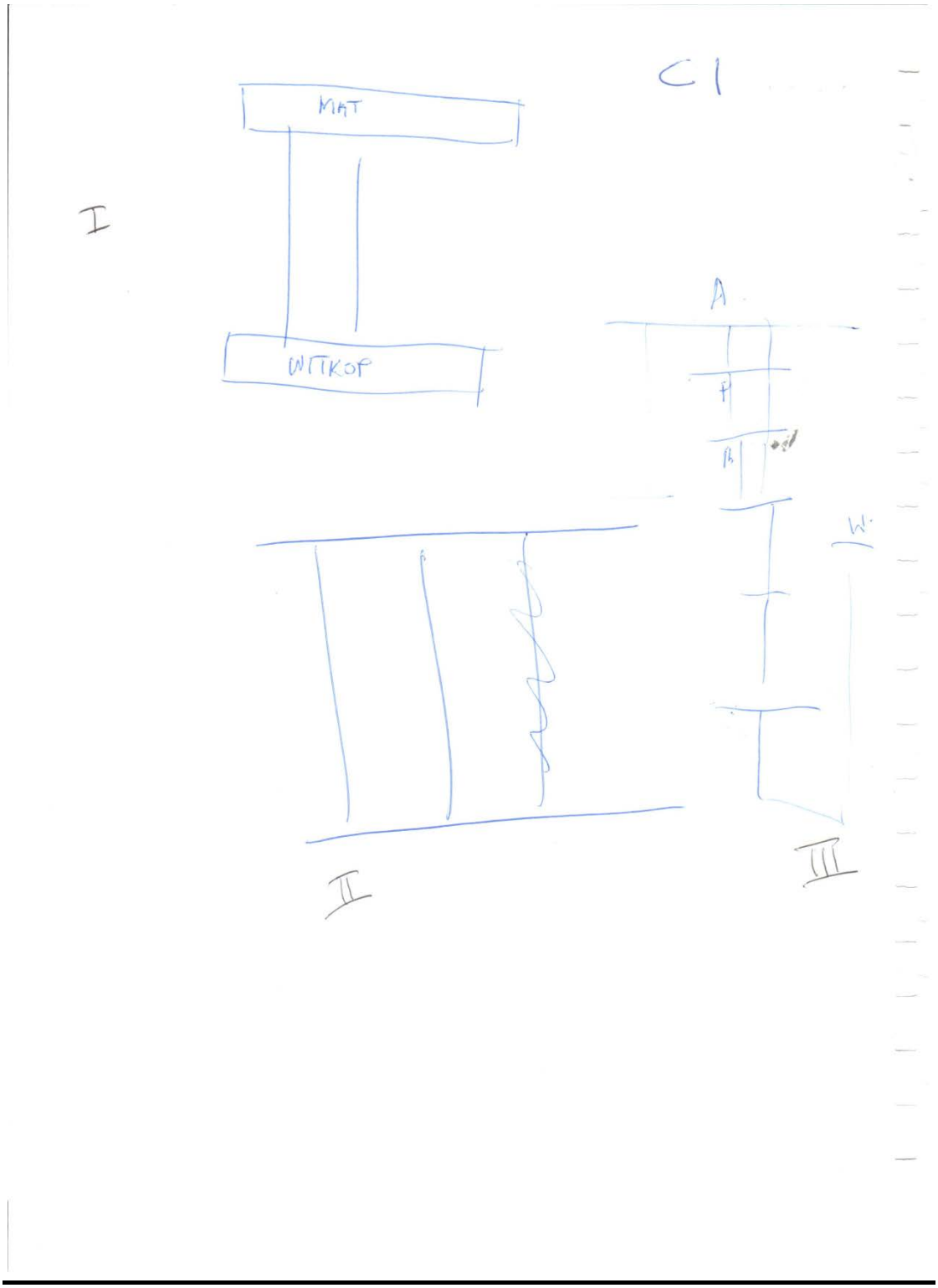
, TFR 3 TRIPPED. CAUSE UNKNOWN. NOT AWARE OF WORK BEING DONE.

, TFR 1 & 2 OVERLOADING. (400MVA TFRS).

, KRUISPUNT ALREADY CLOSED.

KRUISPUNT, ARNOT CLOSED VIA TEMSE.
NO 275kV GEN @
TFR 1 & 2 OVERLOADING STILL
PRAIRIE, RADIAL FEED LOAD REDUCED TO LIMIT OVERLOADING OF ARNOT TFRS.

, TFR 1 & 2 TRIPPED. - CAUSE UNKNOWN.
EXERCISE STOPPED.


C1
MAT
I
WITKOP
A
P
B
W
II
III

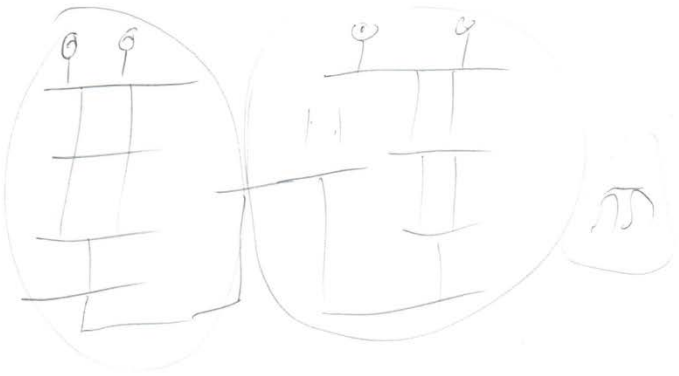
**C2**

Exam 2 C2 26/11/10.

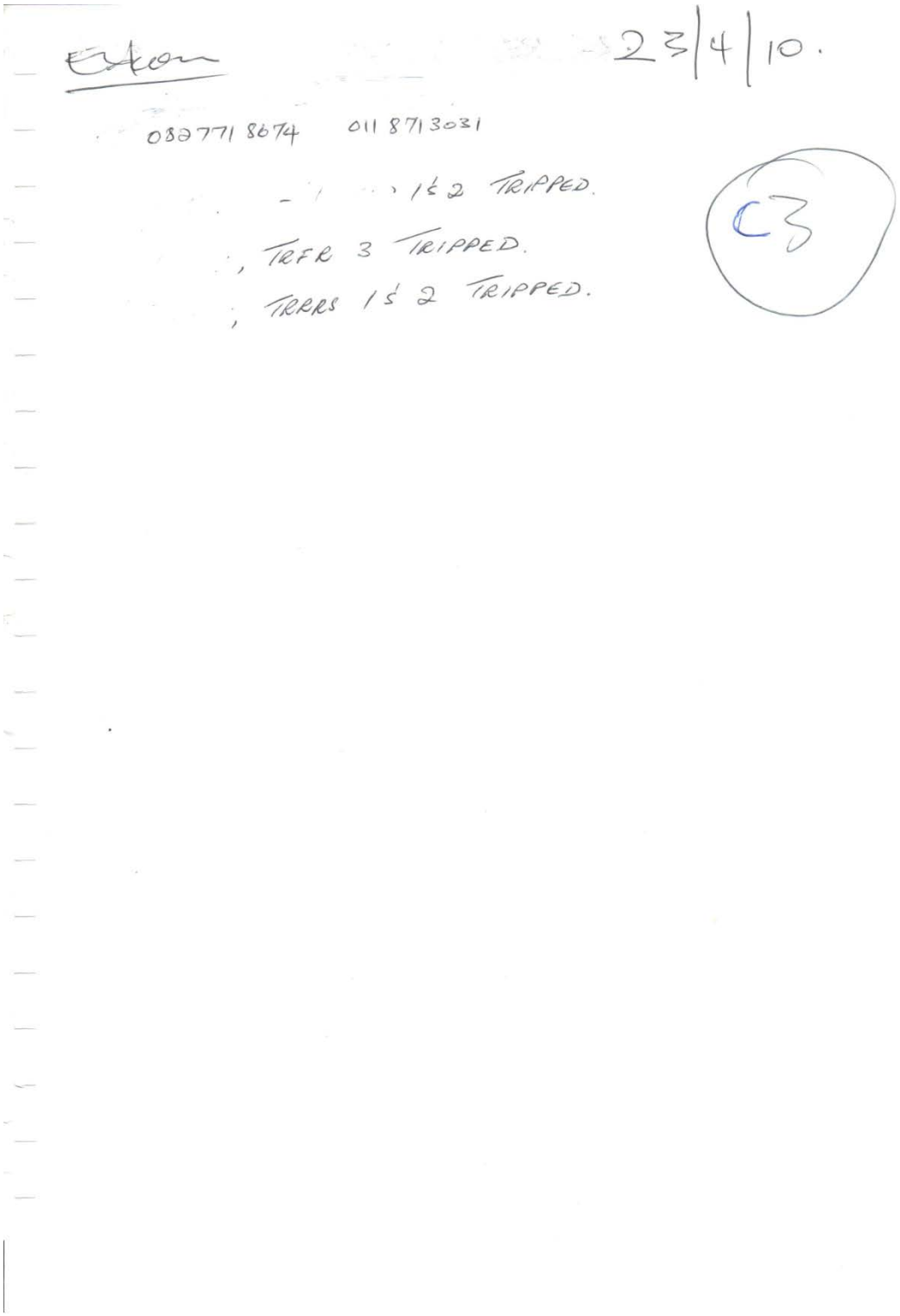
1230-1330

After first line trip will try lines that tripped in once. If unable to return to service, would use Generation and reactive equipment to restore voltages to acceptable levels. At this stage voltages ~~will~~ should be low but acceptable. Will identify next worst contigency, and if time what is safe transfer limit.

On tripping of transformers will imediatly shed load in the area. Best place will be either mozal 400 MW potline or shedding of Rockdale substation 250 MW.



**C3.**


Eskom
23/4/10.
0827718674 0118713031
1 & 2 TRIPPED.
TRFR 3 TRIPPED.
TRRRS 1 & 2 TRIPPED.
C3

No Sketch

**C4**

21/1/10

C4

① Saw the alarm went to overview (Tieline) to see what trip. Where in the network this happened 2 lines. Something major must have happened. Concentrate on the rest of the system.

② to the voltage overview to see what impact on the rest of the station system.

③ Try to stabelize the rest of the system voltages.

DISPLAY etc?

SIMPE
DIGRAM
UNDER
CONTINGENCY



**C5**

83 541 2067

871-3031

1) Low voltages to pix
2) 1+2 trip
3) Trpr 1 trip
4) trpr 2+3 trip

ESKOM

23/4/10

C5

ARNOT MARENSKI

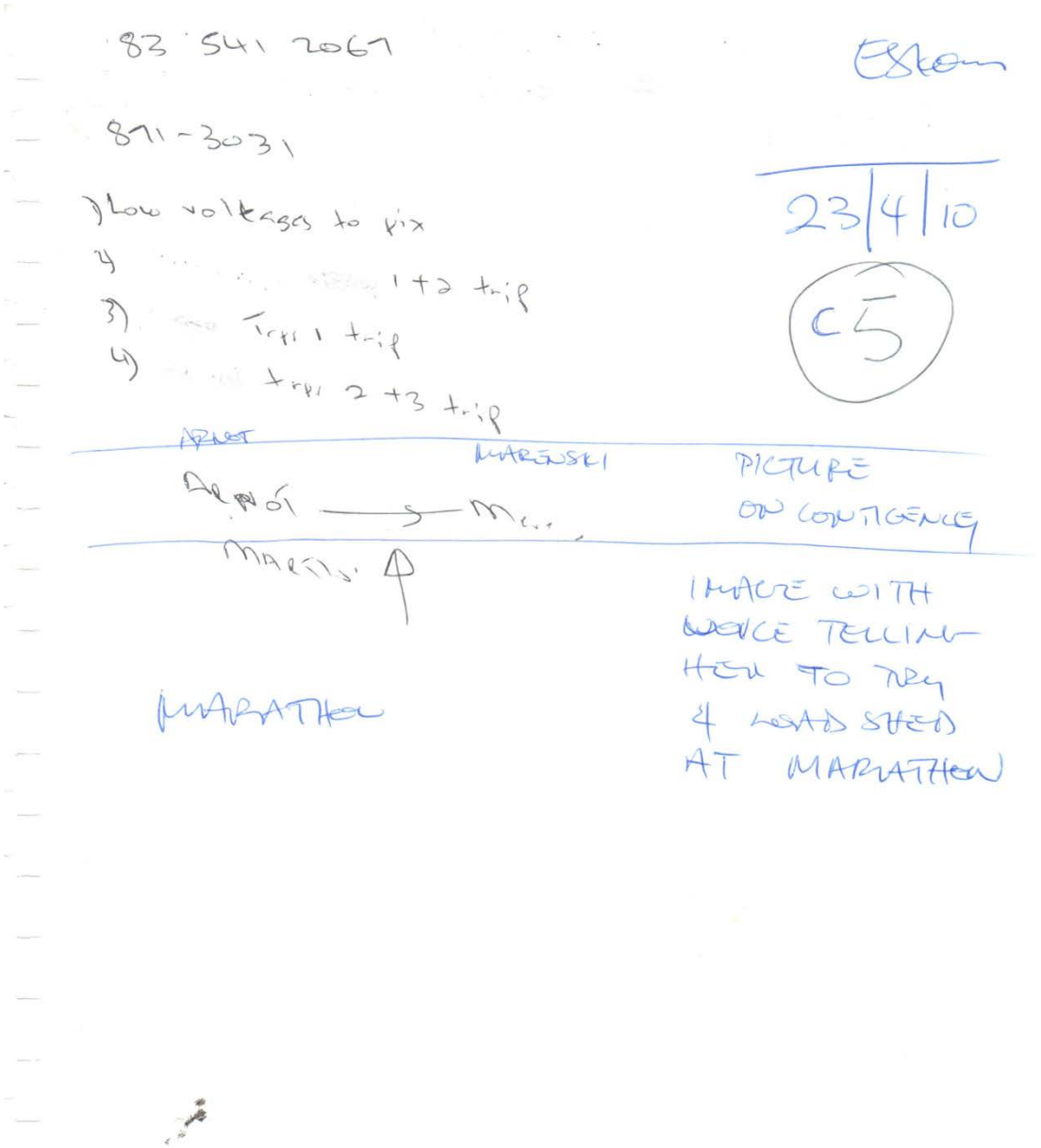
Arnot → Mar...

Marathon

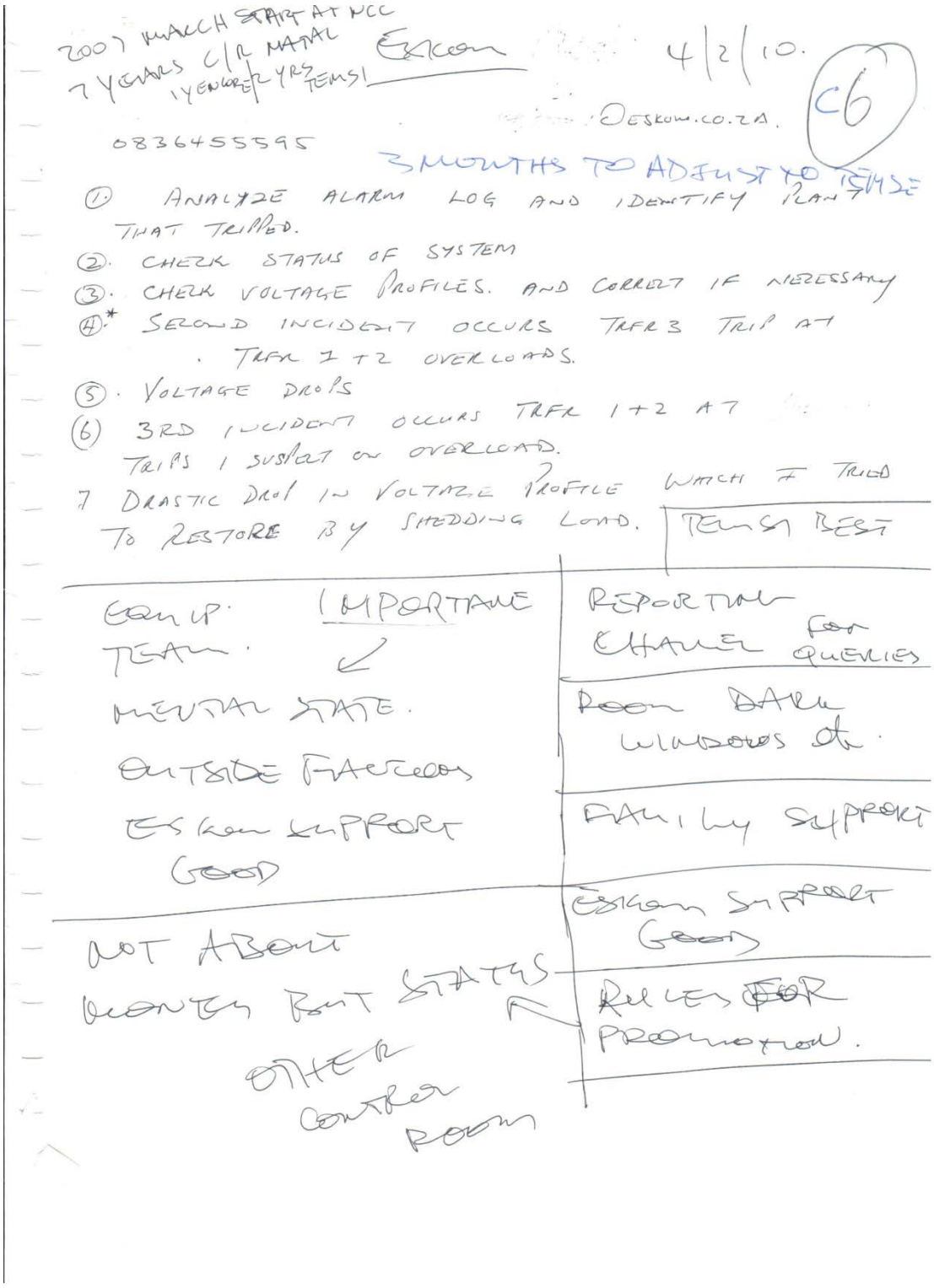
PICTURE ON CONTIGENCY

IMAGE WITH VOICE TELLING HER TO TRY & LOAD SHED AT MARATHON

MARATHON



**C6.**


2007 MARCH START AT MCC
7 YEARS C/R MAINT
1 YEAR 2 YRS ITEMS!
ESKOM
4/2/10.
ESKOM.CO.ZA.
C6
0836455595
3 MONTHS TO ADJUST TO THESE
① ANALYZE ALARM LOG AND IDENTIFY PLANT THAT TRIPPED.
② CHECK STATUS OF SYSTEM
③ CHECK VOLTAGE PROFILES. AND CORRECT IF NECESSARY
④* SECOND INCIDENT OCCURS TRFR 3 TRIP AT . TRFR 1 + 2 OVERLOADS.
⑤ VOLTAGE DROPS
⑥ 3RD INCIDENT OCCURS TRFR 1+2 AT TRIPS 1 SUSPECT ON OVERLOAD.
7 DRASTIC DROP IN VOLTAGE PROFILE WHICH IF TRIED TO RESTORE BY SHEDDING LOAD.
TEAM BEST
CLEAN UP TEAM.
IMPORTANT
MENTAL STATE.
OUTSIDE FACTORS
ESKOM SUPPORT GOOD
REPORTING CHANGES FOR QUERIES
ROOM DARK WINDOWS etc.
FAMILY SUPPORT
NOT ABOUT
MONEY BUT STATUS
ESKOM SUPPORT GOOD
RULES FOR PROMOTION.
OTHER CONTROL ROOM

No sketch…

**C7**

Eskom 4/2/10

14 6 months IN NCC
BEFORE 6 YEARS E/CARE CONTROL Room

@ Eskom.co.za

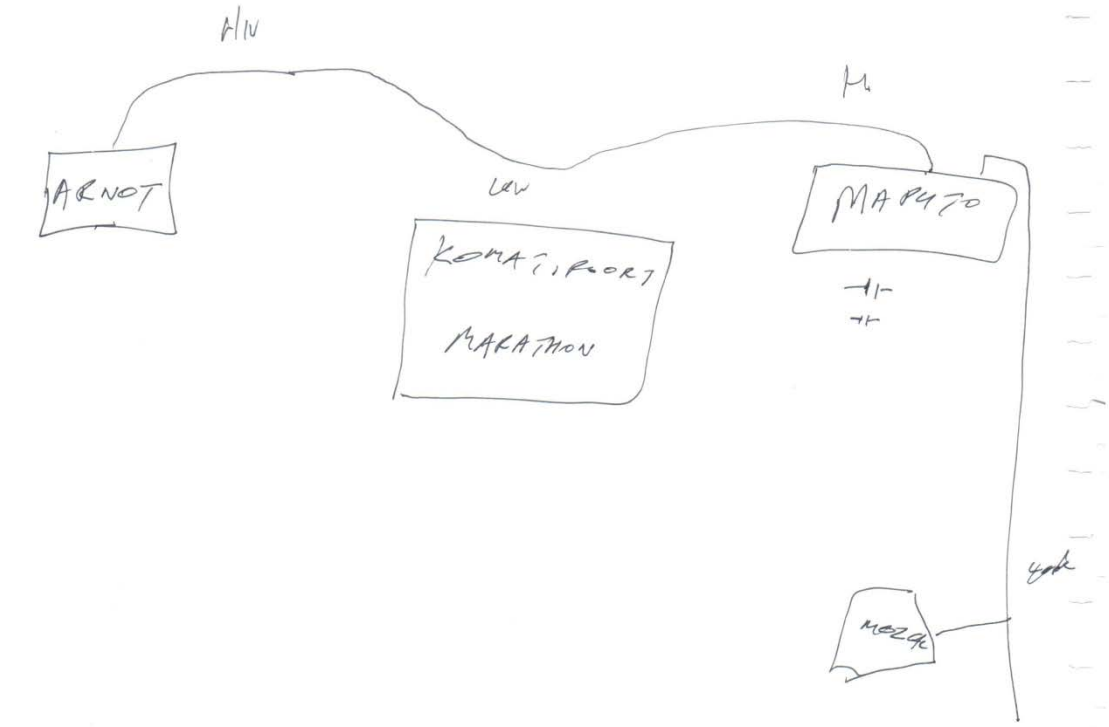
C7

ICD 2 Trip

- Attempt to close back the lines (fail)
Checked voltages and increased Setpoint by 5KV
Foskor CX 2 closed
Checked TRFR1 & 2 tapped up
Desealing CX in service

TRFR TRIPS

TAPPED up MAPUTO TRFR 1
Shed MOZAL PORT (400MW)
CLOSED MAPUTO CX
Shedd MARATHON, Delta 2 132kV shed (80MW)
KOMATIPOORT, KROMDRAAI 22kV bus shed (failed)


ARNOT
KOMATIPOORT
MARATHON
MAPUTO

**C8**

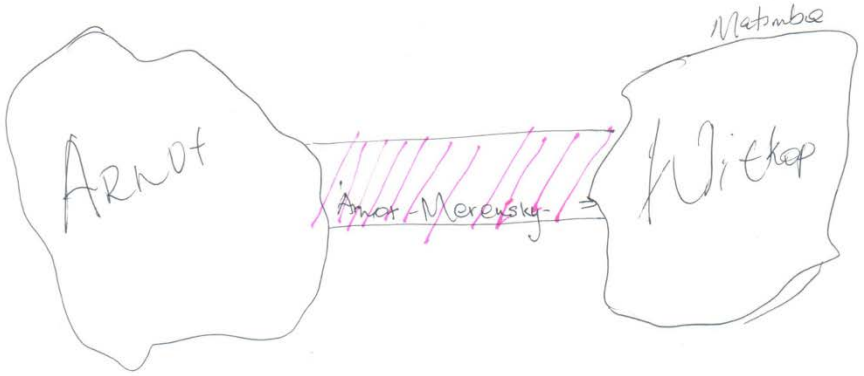
Eskom 18/2/10.

C8

@ eskom.co.za.

1. On the MOTRACO tieline, the Maputo 275kV CX 4 was not in service. Voltage at Maputo was 398,5k On the 400kV and the voltage reference on the 275kV was out of scan. I looked at the other 275 kV voltages ie, Irfulene and Komatipoort, Maratha and based on what I saw, 278 kV then assumed Maputo also around there (same network) then requested the CX4 to be closed. Voltage increased but not much.
2. I checked the Natal, WC, EC to see if all the Caps were in service, voltages were ok.
3. I was told that we do not have 275 kV gens @ and I realised that if anything happened there, there would be a problem.
4. 1+2 then tripped. I asked to try the lines in but they could not be switched in, so there was a permanent fault or fire under the lines. Requested (dispatched) someone - line patrol, and also mentioned that fault investigations to investigate.
5. In the meantime I knew that Witkop will have to be supplied from via the 400kV and through Esselen - Pelly 275 kV network.
6. I requested the Mercury CX to be closed.
7. Then trfr 3 at Arnot tripped. The picked up load and with trfr 3 tripping, I knew I had problems on the 275 kV network.

8. I requested Matla-Esselen-kruispunt Tee to be reconfigured as a Matla-kruispunt so that some of the 275kV load can be supplied from Matla.
9. With the Witkop-Tabor-Spencer network voltage decreasing I then requested load to be shed at Spencer and Tabor, at the same time requested load to be shed at Simplon as well.
10. On the Motraco ties I requested Komatipoort, Impulane to be opened.
11. Transformers 1 & 2 at [redacted] then tripped on O/L, and there was also a voltage slide on that network.
12. Requested Duiwa and Kendal voltage to be raised.



**C9.**

Eskom 16/4/10.

@ eskom.co.za 0824015856

C9

1. took over shift and started going through the voltages throughout the network.
2. First went through Western Cape Voltages Closed Stikland CX, noted that both Palmiet's were in gen, north ring Koeberg, Aries etc Voltage's OK
3. Went to go through Eastern Cape Voltages Closed Buffalo CX. Noted that Delphi RX was still out of service.
4. Went through Freestate Voltages Noted that Theseus CX was closed + Leander CX was open. Also opened Beta RX2.
5. Was busy going through Central region voltages and topping transformer at [redacted] when [redacted] H2 tripped. Notified Manager on shift of trip and tried to close at [redacted] - failed to close. tried to close with sp, Matimba 2- failed to close
6. Ran [redacted] Trip's 1+2 275KV Brk's

tripped, noted that Trfr 3 was overloading

(7) Before this I asked Jan to pick up voltages at Kendal, Duvha, Lethabo, Matla and Matmiba. Also noted that Matmiba had 4 gens on and did not need to take spinning due to there being to few lines for ammount of generation.

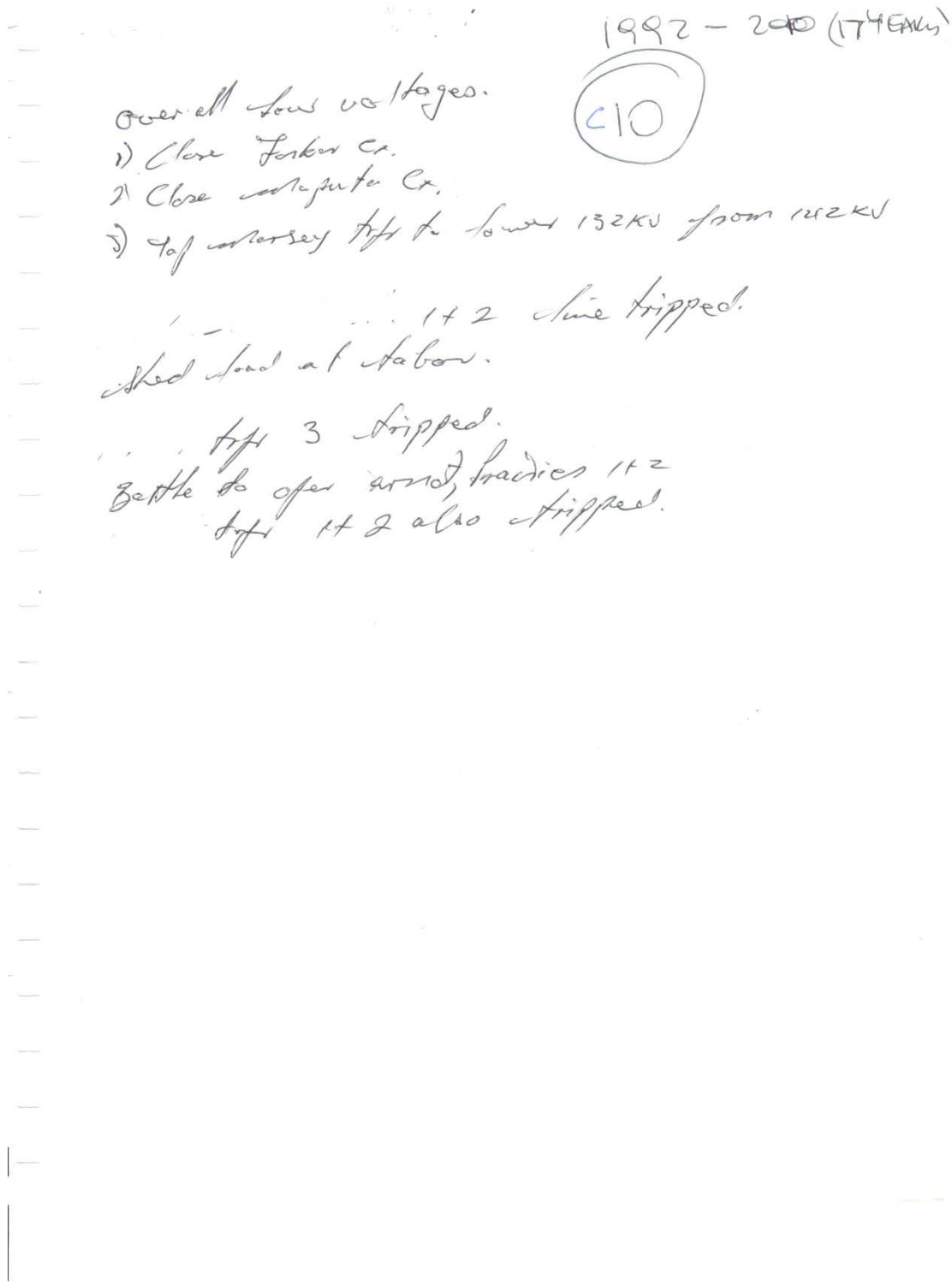
(8) Requested load to be shed at Rockdale ± 100MW's

(9) Then Trfr 3 tripped and the wheels feel off

C9

No sketch

**C10.**




No sketch

**C11**

Eskom

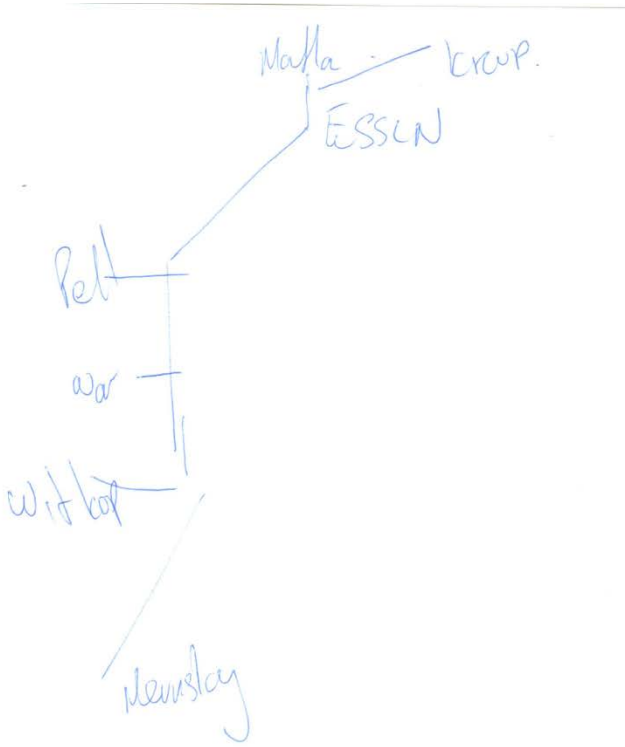
16/4/10

@ eskom.co.za

088 633 3189

C11

- 1+2 trip
- Check voltages
- Shifted load away from WITKOP + WARB + Pelly.
- ESSLN Voltage low so pick up Voltage Metlathet
- tried closing in WIT, MAT 1+2
- Check voltages no slide so left it.
- the ARNOT TRFR 3 trip.
- Want to put in MATLA + Kruspin but
  Bric at Kruns not avaible.
- This would have de-loaded ARNTO TRFR
- But this would have drop voltage at
  ESSLN.
- TRFR TRIP - then load shedded.


Malla
Group
ESSLN
Belt
war
without
Newsday


C 11

**C12**

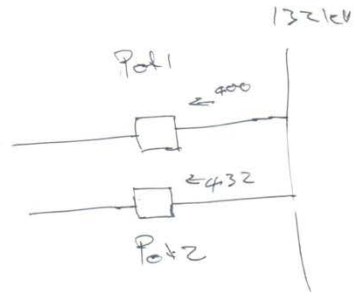
S/PAN Eskom 11/2/10.

@ESKOM.CO.ZA.

ENLARE 1998
TEMMY 2008

C12

After being told that - Midas 1 was on outage and Matimba, Pluto is on transfer/Bypass.
My thinking was the excersize will be about
I started by going through my system voltage around that area including - Arnont down to Merensky.
- The first fault occured ⇒ 1+2 tripped resulting in low voltage around Warambad, Witkop, Pelly area and I tried to correct voltage by closing foskor Cx1, peaked up voltage at Arnot Power station until the station cannot export more MVAr
I felt I could not use . as both witkop lines are out.
Voltage ~~co~~ recovered to a satisfactory region but not back to normal
- , Trfr 3 tripped resulting in Trfr 1+2 overloading
- I took spinning on 400 kV Gens of about 200mw ovoiding to over react by shedding on the 275kV
- Both trfr 1 & 2 tripped aswel due to over load
- Motraco voltage was not much affected by the two traformer that have trip. I had it in my mind that I can open one of the pot lines but I decided to close the 275kV Cx4 which was open at the time to avoid high voltage from resulting in that motraco area.




REORE
EQUIP.
ENV.
OPORTUN. — STUDY.
FAMILY etc.

C12

**C13**

Estan 28/1/10.

C13

- Checked Network Status
  Mat – Midas line out
  Midas – Pluto out
- Thought about the Networ worst contingency
- Sudenly heard the alarm
  - checked
  - saw matimb – with 1 ϕ 2 lines out
  - Checked the TSS limits
  - Because 2 gens were already out didn't affect it but the next could...
- Frequency increased from 50.04 – 50.15
  Emediately thout that we lost some load
- Thought of telling the advisor what occurr and
- Checked Voltages were fine
- Told the matm station to decrease 200MW
- Voltages at ~~out~~ Merency were down
- ~~Transformer~~ Checked the whether the Backfeeds transformer lines were not overload
- Arlam: 1, 2 transformer tripped
  frequency increased
  immediately I thought we lost a big chank of load –
  – though of quick gens to pull down Drakies and Palmiet..
- Checked effect of load loss, Back feeds
- Thought of Isolating the affected area so not to ~~collapse~~ affect the entire Network




C13

**C14**

10 EMOU
2 [illegible]

14

1) Voltage Profile in general was inadequate, speacilly North East and Northern region. Matimba requested to pick up Voltage, but was at max. Leteabo/ Matea also requested to pick up Voltage but was at max.

2) 1/2 lines tripped. Voltage slide in the northern, central and north east areas. Shed about 60 mw at Witkop (Pietersburg), and 40 mw at Pelly to stabilise the network.

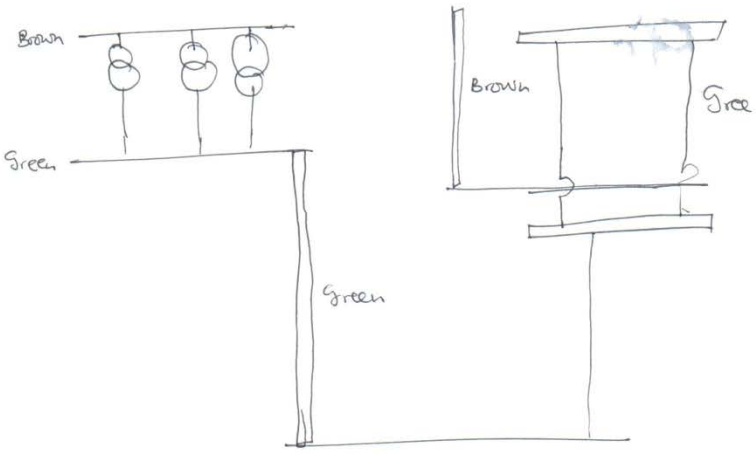
3) Attempt to close Matimba - Witkop lines failed due to permanent fault.

4) A 700 kv CX2 was closed, which was in open position.
Maputo CX4

5) Trf 3, Tripped resulting in remaining transformer to overload. While attempting to stabilise the network, both remaining trfr's at Tripped.

6) Mozal, Potline 1 shed due to a Voltage collapse after the two transformers tripped.

7) Further loadshedding instructed in North East Region.




C14

# APPENDIX B

Below are the copies of the Form 2 submissions by the controllers describing how they feel when they work alone in the control room during a contingency.

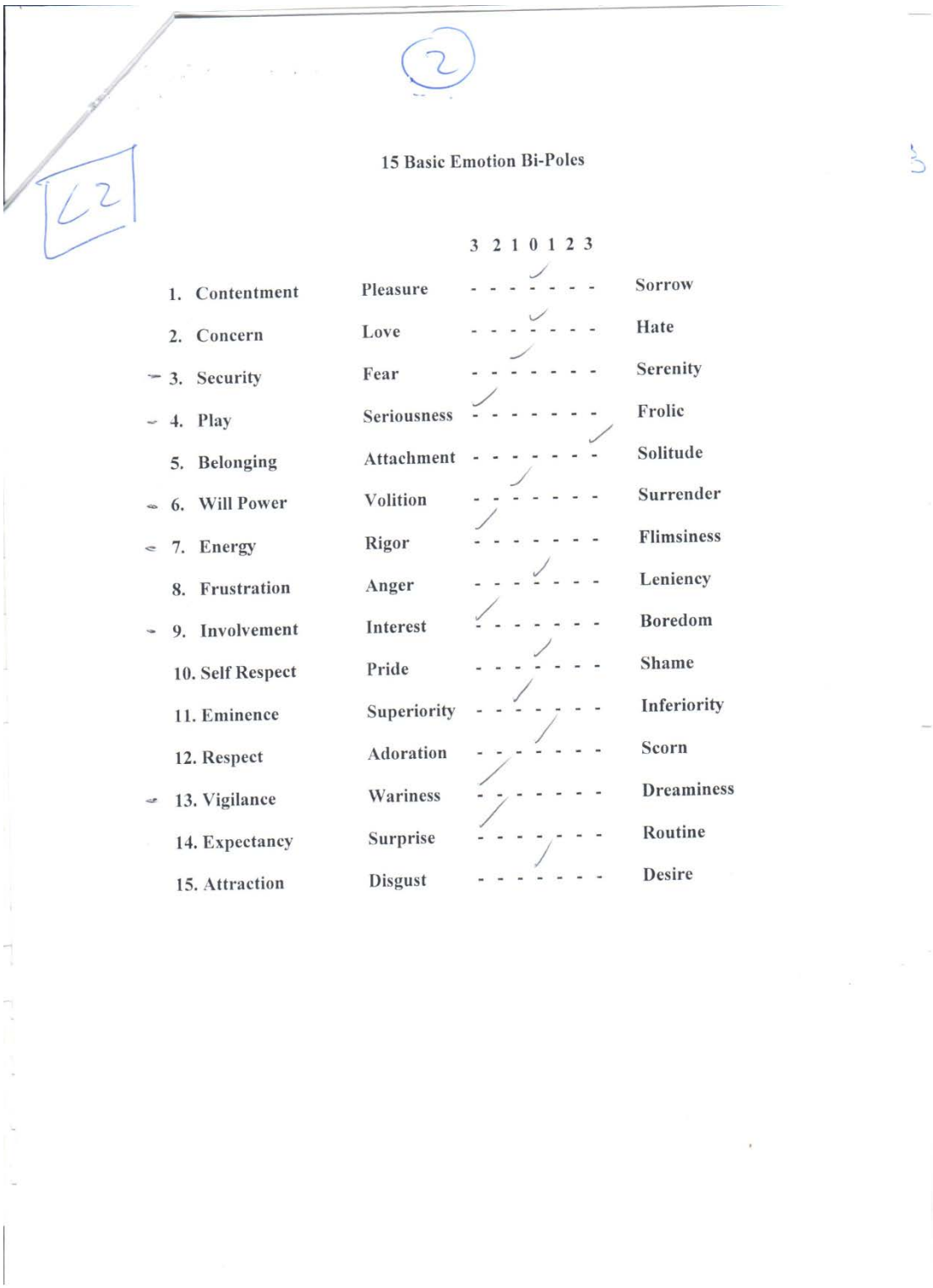
**C1**



15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - - - - X - | Sorrow |
| 2. Concern | Love | - - - - - X - | Hate |
| 3. Security | Fear | - X - - - - - | Serenity |
| 4. Play | Seriousness | X - - - - - - | Frolic |
| 5. Belonging | Attachment | - - - - - - X | Solitude |
| 6. Will Power | Volition | - X - - - - - | Surrender |
| 7. Energy | Rigor | - X - - - - - | Flimsiness |
| 8. Frustration | Anger | X - - - - - - | Leniency |
| 9. Involvement | Interest | X - - - - - - | Boredom |
| 10. Self Respect | Pride | X - - - - - - | Shame |
| 11. Eminence | Superiority | X - - - - - - | Inferiority |
| 12. Respect | Adoration | X - - - - - - | Scorn |
| 13. Vigilance | Wariness | X - - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - X - - - - - | Routine |
| 15. Attraction | Disgust | - - - - - X - | Desire |

**C2**



15 Basic Emotion Bi-Poles

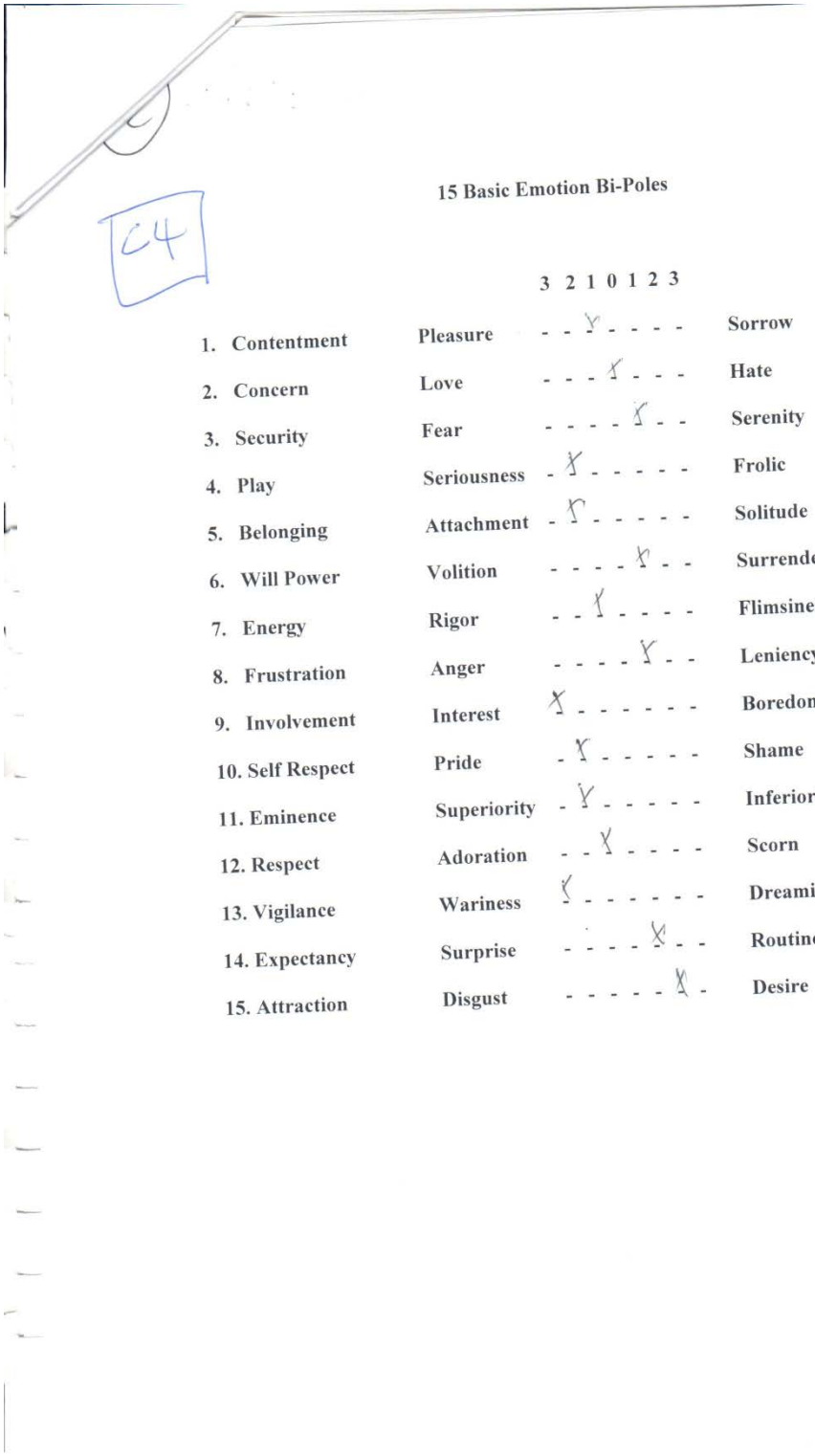
| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - - ✓ - - - | Sorrow |
| 2. Concern | Love | - - - ✓ - - - | Hate |
| 3. Security | Fear | - - ✓ - - - - | Serenity |
| 4. Play | Seriousness | - ✓ - - - - - | Frolic |
| 5. Belonging | Attachment | - - - - - - ✓ | Solitude |
| 6. Will Power | Volition | - - ✓ - - - - | Surrender |
| 7. Energy | Rigor | - ✓ - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - ✓ - - - | Leniency |
| 9. Involvement | Interest | - ✓ - - - - - | Boredom |
| 10. Self Respect | Pride | - - - ✓ - - - | Shame |
| 11. Eminence | Superiority | - - ✓ - - - - | Inferiority |
| 12. Respect | Adoration | - - - ✓ - - - | Scorn |
| 13. Vigilance | Wariness | - ✓ - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - ✓ - - - - - | Routine |
| 15. Attraction | Disgust | - - - - - - ✓ | Desire |

**C3**

15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - - - - - - | Sorrow |
| 2. Concern | Love | - - - - - - - | Hate |
| 3. Security | Fear | - - X - - - - | Serenity |
| 4. Play | Seriousness | X - - - - - - | Frolic |
| 5. Belonging | Attachment | X - - - - - - | Solitude |
| 6. Will Power | Volition | X - - - - - - | Surrender |
| 7. Energy | Rigor | X - - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - X - - - | Leniency |
| 9. Involvement | Interest | X - - - - - - | Boredom |
| 10. Self Respect | Pride | X - - - - - - | Shame |
| 11. Eminence | Superiority | X - - - - - - | Inferiority |
| 12. Respect | Adoration | - - - - - - - | Scorn |
| 13. Vigilance | Wariness | X - - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - X - - - - - | Routine |
| 15. Attraction | Disgust | - - X - - - - | Desire |

**C4**

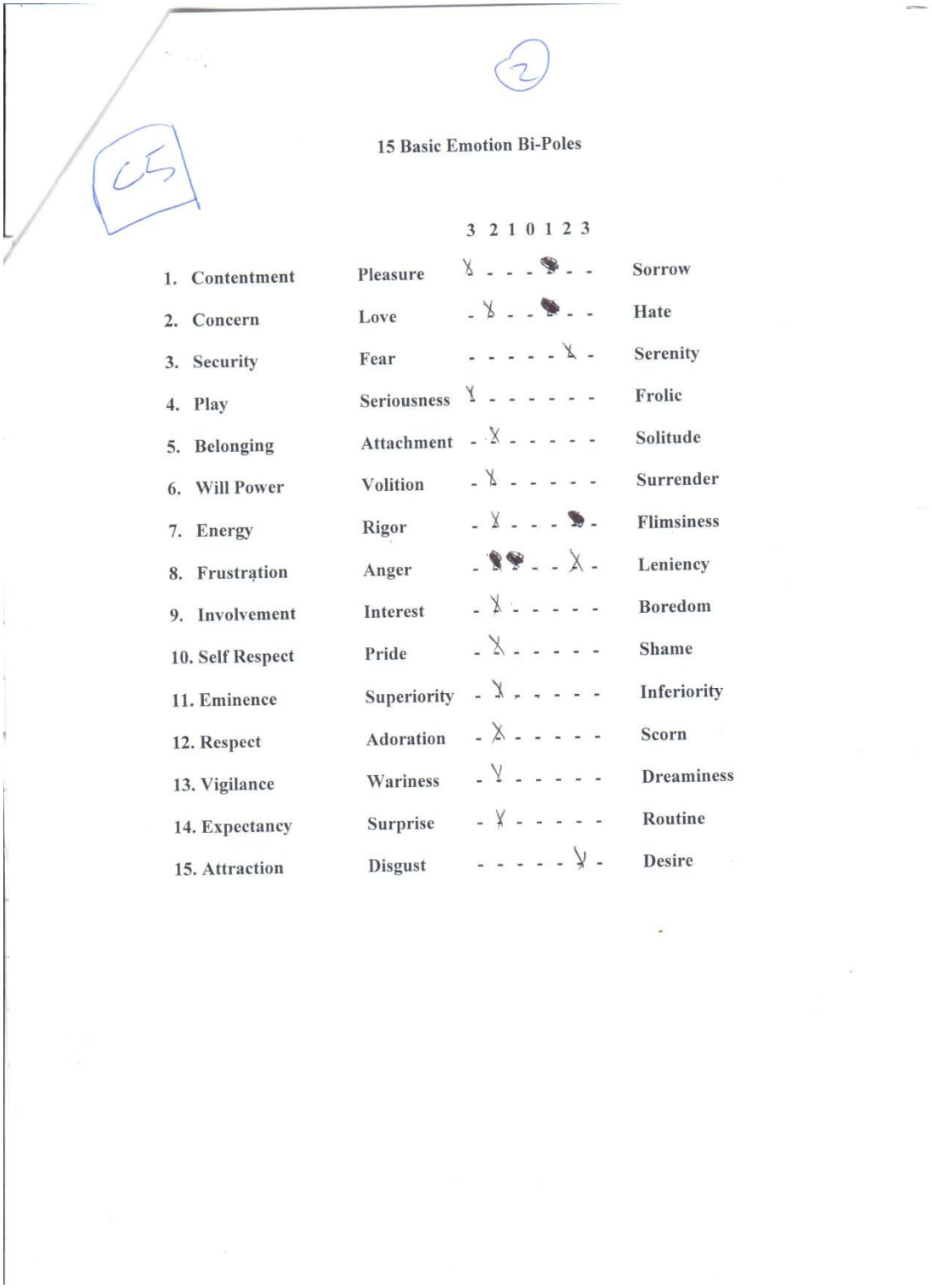


C4

15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - X - - - - | Sorrow |
| 2. Concern | Love | - - - X - - - | Hate |
| 3. Security | Fear | - - - - X - - | Serenity |
| 4. Play | Seriousness | - X - - - - - | Frolic |
| 5. Belonging | Attachment | - X - - - - - | Solitude |
| 6. Will Power | Volition | - - - - X - - | Surrender |
| 7. Energy | Rigor | - - X - - - - | Flimsiness |
| 8. Frustration | Anger | - - - - X - - | Leniency |
| 9. Involvement | Interest | X - - - - - - | Boredom |
| 10. Self Respect | Pride | - X - - - - - | Shame |
| 11. Eminence | Superiority | - X - - - - - | Inferiority |
| 12. Respect | Adoration | - - X - - - - | Scorn |
| 13. Vigilance | Wariness | X - - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - - - - X - - | Routine |
| 15. Attraction | Disgust | - - - - - X - | Desire |

**C5**



15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | | Sorrow |
| 2. Concern | Love | | Hate |
| 3. Security | Fear | | Serenity |
| 4. Play | Seriousness | | Frolic |
| 5. Belonging | Attachment | | Solitude |
| 6. Will Power | Volition | | Surrender |
| 7. Energy | Rigor | | Flimsiness |
| 8. Frustration | Anger | | Leniency |
| 9. Involvement | Interest | | Boredom |
| 10. Self Respect | Pride | | Shame |
| 11. Eminence | Superiority | | Inferiority |
| 12. Respect | Adoration | | Scorn |
| 13. Vigilance | Wariness | | Dreaminess |
| 14. Expectancy | Surprise | | Routine |
| 15. Attraction | Disgust | | Desire |

**C6**

THE FOLLOWING IS A TENTATIVE LIST OF 15 BASIC EMOTIONS:

NAME: DATE: TOPIC:

1) Contentment (Pleasure - 1 2 3 4 5 (6) 7 Sorrow)

2) Concern (Love - 1 2 3 4 5 (6) 7 Hate)

3) Security (Fear - 1 2 (3) 4 5 6 7 Serenity)

4) Play (Seriousness 1 (2) 3 4 5 6 7 Frolic)

5) Belonging (Attachment 1 2 3 (4) 5 6 7 Solitude)

6) Will power (Volition - 1 2 3 (4) 5 6 7 Surrender)

7) Energy (Rigor - 1 2 3 (4) 5 6 7 Flimsiness)

8) Frustration (Anger - 1 2 3 (4) 5 6 7 Leniency)

9) Involvement (Interest - 1 2 (3) 4 5 6 7 Boredom)

10) SelfRespect (Pride - 1 2 3 (4) 5 6 7 Shame)

11) Eminence (Superiority 1 2 (3) 4 5 6 7 Inferiority)

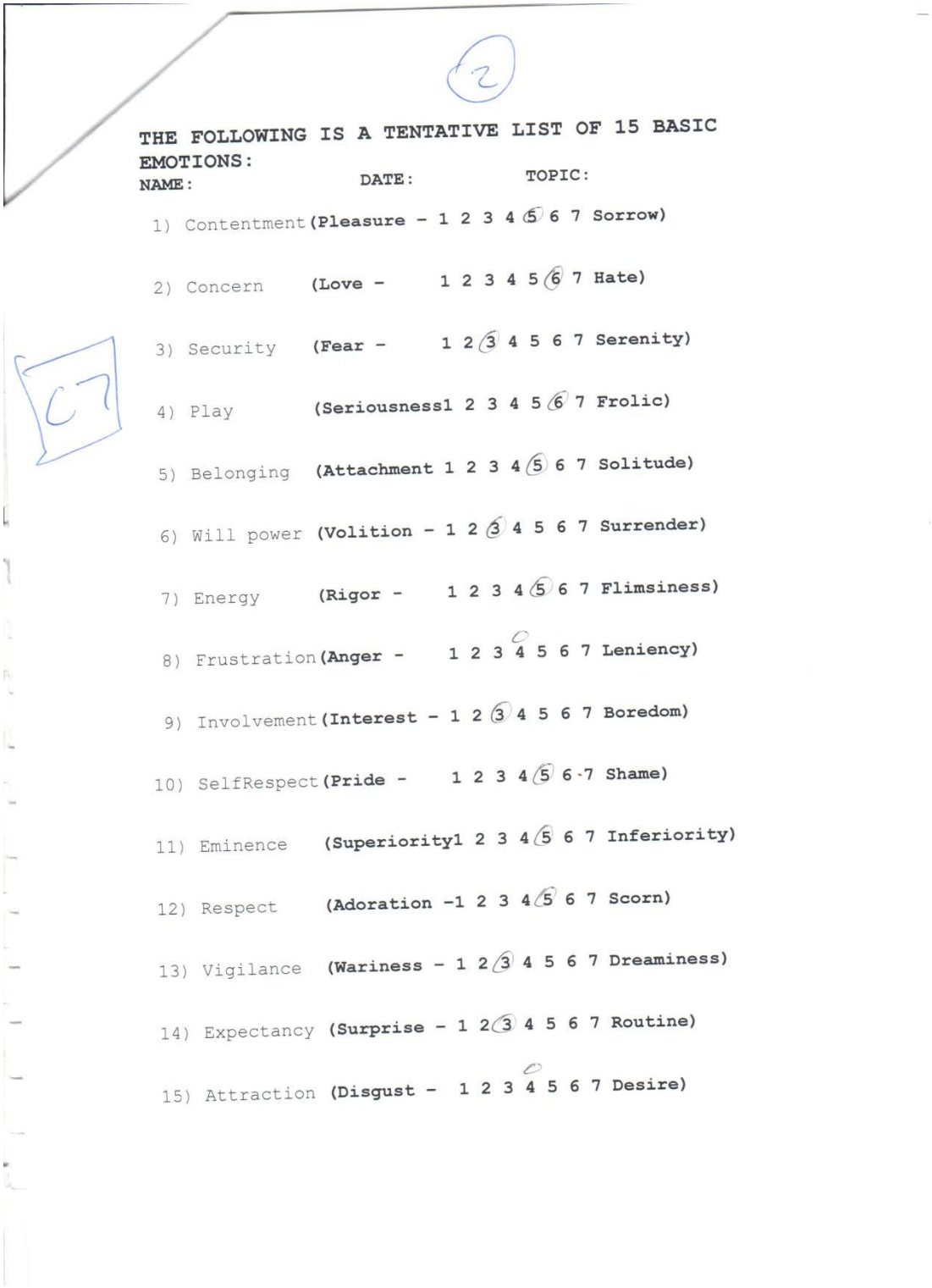
12) Respect (Adoration -1 2 3 (4) 5 6 7 Scorn)

13) Vigilance (Wariness - 1 (2) 3 4 5 6 7 Dreaminess)

14) Expectancy (Surprise - 1 (2) 3 4 5 6 7 Routine)

15) Attraction (Disgust - 1 2 (3) 4 5 6 7 Desire)

**C7**



THE FOLLOWING IS A TENTATIVE LIST OF 15 BASIC EMOTIONS:

NAME: DATE: TOPIC:

1) Contentment (Pleasure – 1 2 3 4 5 6 7 Sorrow)

2) Concern (Love – 1 2 3 4 5 6 7 Hate)

3) Security (Fear – 1 2 3 4 5 6 7 Serenity)

4) Play (Seriousness 1 2 3 4 5 6 7 Frolic)

5) Belonging (Attachment 1 2 3 4 5 6 7 Solitude)

6) Will power (Volition – 1 2 3 4 5 6 7 Surrender)

7) Energy (Rigor – 1 2 3 4 5 6 7 Flimsiness)

8) Frustration (Anger – 1 2 3 4 5 6 7 Leniency)

9) Involvement (Interest – 1 2 3 4 5 6 7 Boredom)

10) SelfRespect (Pride – 1 2 3 4 5 6 7 Shame)

11) Eminence (Superiority 1 2 3 4 5 6 7 Inferiority)

12) Respect (Adoration – 1 2 3 4 5 6 7 Scorn)

13) Vigilance (Wariness – 1 2 3 4 5 6 7 Dreaminess)

14) Expectancy (Surprise – 1 2 3 4 5 6 7 Routine)

15) Attraction (Disgust – 1 2 3 4 5 6 7 Desire)

**C8**

2.

(2)

C8

15 Basic Emotion Bi-Poles

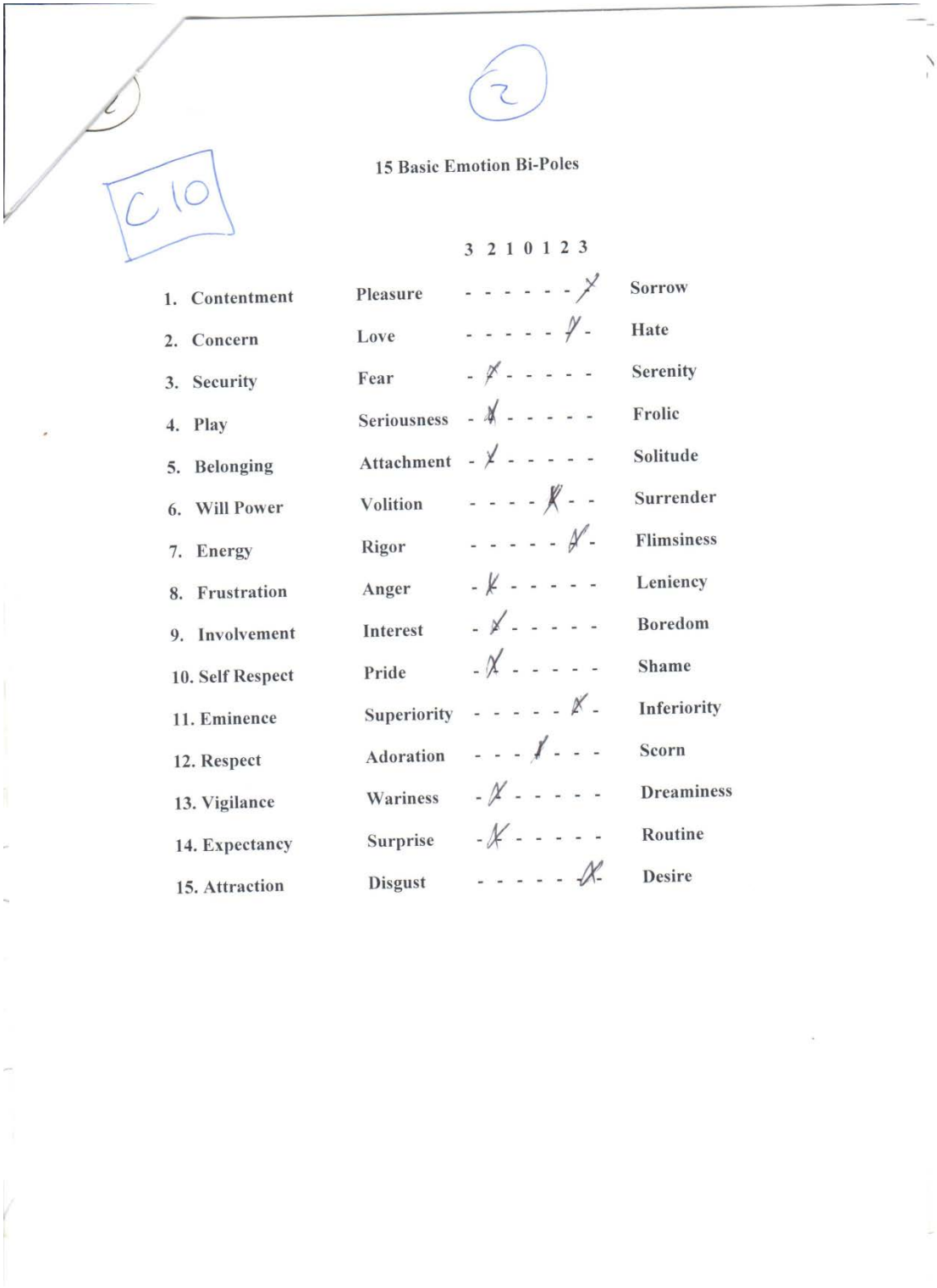
| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - X - - - - | Sorrow |
| 2. Concern | Love | - - X - - - - | Hate |
| 3. Security | Fear | - - X - - - - | Serenity |
| 4. Play | Seriousness | - X - - - - - | Frolic |
| 5. Belonging | Attachment | - - X - - - - | Solitude |
| 6. Will Power | Volition | - - X - - - - | Surrender |
| 7. Energy | Rigor | - X - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - - X - - | Leniency |
| 9. Involvement | Interest | X - - - - - - | Boredom |
| 10. Self Respect | Pride | X - - - - - - | Shame |
| 11. Eminence | Superiority | - X - - - - - | Inferiority |
| 12. Respect | Adoration | - X - - - - - | Scorn |
| 13. Vigilance | Wariness | X - - - - - - | Dreaminess |
| 14. Expectancy | Surprise | X - - - - - - | Routine |
| 15. Attraction | Disgust | - - - - - X - | Desire |

**C9**

15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - 1 - - - - | Sorrow |
| 2. Concern | Love | - - - 0 - - - | Hate |
| 3. Security | Fear | - - 1 - - - - | Serenity |
| 4. Play | Seriousness | 3 - - - - - - | Frolic |
| 5. Belonging | Attachment | - - - - 1 - - | Solitude |
| 6. Will Power | Volition | - 2 - - - - - | Surrender |
| 7. Energy | Rigor | - 2 - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - 0 - - - | Leniency |
| 9. Involvement | Interest | 3 - - - - - - | Boredom |
| 10. Self Respect | Pride | 3 - - - - - - | Shame |
| 11. Eminence | Superiority | 3 - - - - - - | Inferiority |
| 12. Respect | Adoration | - - 1 - - - - | Scorn |
| 13. Vigilance | Wariness | - 2 - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - - - - 1 - - | Routine |
| 15. Attraction | Disgust | - - - - - 2 - | Desire |

**C10**



15 Basic Emotion Bi-Poles

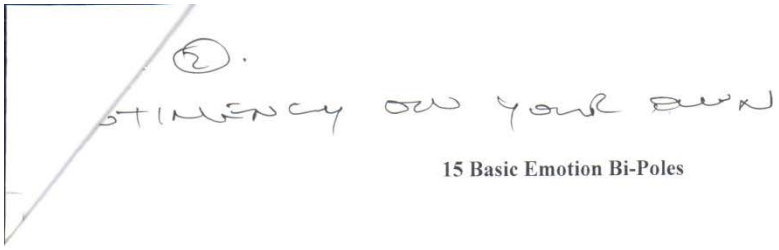
| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - - - - - X | Sorrow |
| 2. Concern | Love | - - - - - X - | Hate |
| 3. Security | Fear | - X - - - - - | Serenity |
| 4. Play | Seriousness | - X - - - - - | Frolic |
| 5. Belonging | Attachment | - X - - - - - | Solitude |
| 6. Will Power | Volition | - - - - X - - | Surrender |
| 7. Energy | Rigor | - - - - - X - | Flimsiness |
| 8. Frustration | Anger | - X - - - - - | Leniency |
| 9. Involvement | Interest | - X - - - - - | Boredom |
| 10. Self Respect | Pride | - X - - - - - | Shame |
| 11. Eminence | Superiority | - - - - - X - | Inferiority |
| 12. Respect | Adoration | - - - X - - - | Scorn |
| 13. Vigilance | Wariness | - X - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - X - - - - - | Routine |
| 15. Attraction | Disgust | - - - - - X - | Desire |

**C11**

15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - X - - - - - | Sorrow |
| 2. Concern | Love | - - X - - - - - | Hate |
| 3. Security | Fear | - - - - X - - - | Serenity |
| 4. Play | Seriousness | - - - - X - - - | Frolic |
| 5. Belonging | Attachment | - - - - - X - - | Solitude |
| 6. Will Power | Volition | - - - - X - - - | Surrender |
| 7. Energy | Rigor | - - - - X - - - | Flimsiness |
| 8. Frustration | Anger | - - - - X - - - | Leniency |
| 9. Involvement | Interest | - - X - - - - - | Boredom |
| 10. Self Respect | Pride | - - X - - - - - | Shame |
| 11. Eminence | Superiority | - - X - - - - - | Inferiority |
| 12. Respect | Adoration | - - - - X - - - | Scorn |
| 13. Vigilance | Wariness | - - - - X - - - | Dreaminess |
| 14. Expectancy | Surprise | - - X - - - - - | Routine |
| 15. Attraction | Disgust | - - - - - X - - | Desire |

**C12**



(2).
STINENCY ON YOUR OWN

**15 Basic Emotion Bi-Poles**

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - - - ✓ - - | Sorrow |
| 2. Concern | Love | - - - - - ✓ - | Hate |
| 3. Security | Fear | - - ✓ - - - - | Serenity |
| 4. Play | Seriousness | - ✓ - - - - - | Frolic |
| 5. Belonging | Attachment | - - - - ✓ - - | Solitude |
| 6. Will Power | Volition | - - - ✓ - - - | Surrender |
| 7. Energy | Rigor | - - - - ✓ - - | Flimsiness |
| 8. Frustration | Anger | - - ✓ - - - - | Leniency |
| 9. Involvement | Interest | - - - ✓ - - - | Boredom |
| 10. Self Respect | Pride | - - - - - ✓ - | Shame |
| 11. Eminence | Superiority | - - - - ✓ - - | Inferiority |
| 12. Respect | Adoration | - - - - ✓ - - | Scorn |
| 13. Vigilance | Wariness | - - - ✓ - - - | Dreaminess |
| 14. Expectancy | Surprise | - - ✓ - - - - | Routine |
| 15. Attraction | Disgust | - ✓ - - - - - | Desire |

C12

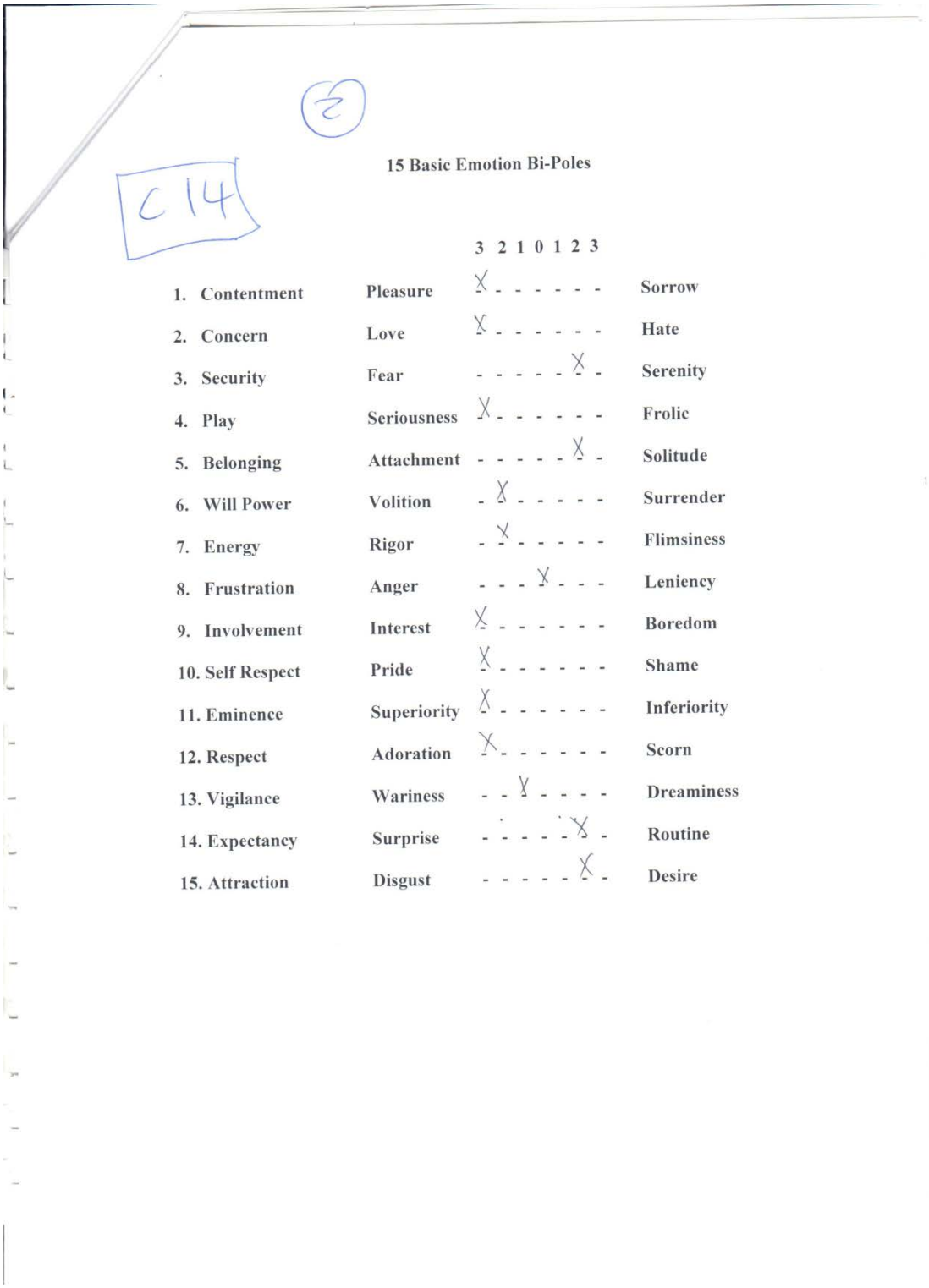
**C13**



15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | - - x - - - - | Sorrow |
| 2. Concern | Love | - x - - - - - | Hate |
| 3. Security | Fear | - - - x - - - | Serenity |
| 4. Play | Seriousness | x - - - - - - | Frolic |
| 5. Belonging | Attachment | - - x - - - - | Solitude |
| 6. Will Power | Volition | x - - - - - - | Surrender |
| 7. Energy | Rigor | x - - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - - - - x | Leniency |
| 9. Involvement | Interest | - x - - - - - | Boredom |
| 10. Self Respect | Pride | x - - - - - - | Shame |
| 11. Eminence | Superiority | x - - - - - - | Inferiority |
| 12. Respect | Adoration | - x - - - - - | Scorn |
| 13. Vigilance | Wariness | - x - - - - - | Dreaminess |
| 14. Expectancy | Surprise | - - x - - - - | Routine |
| 15. Attraction | Disgust | - - - x - - - | Desire |

**C14**



(2)

C14

15 Basic Emotion Bi-Poles

| | | 3 2 1 0 1 2 3 | |
|---|---|---|---|
| 1. Contentment | Pleasure | X - - - - - - | Sorrow |
| 2. Concern | Love | X - - - - - - | Hate |
| 3. Security | Fear | - - - - - X - | Serenity |
| 4. Play | Seriousness | X - - - - - - | Frolic |
| 5. Belonging | Attachment | - - - - - X - | Solitude |
| 6. Will Power | Volition | - X - - - - - | Surrender |
| 7. Energy | Rigor | - X - - - - - | Flimsiness |
| 8. Frustration | Anger | - - - X - - - | Leniency |
| 9. Involvement | Interest | X - - - - - - | Boredom |
| 10. Self Respect | Pride | X - - - - - - | Shame |
| 11. Eminence | Superiority | X - - - - - - | Inferiority |
| 12. Respect | Adoration | X - - - - - - | Scorn |
| 13. Vigilance | Wariness | - - X - - - - | Dreaminess |
| 14. Expectancy | Surprise | - - - - - X - | Routine |
| 15. Attraction | Disgust | - - - - - X - | Desire |

# APPENDIX C

TEMSE and ENCOR screen samples.

Substation layout screen.

This shows substation layouts with bus bars, power lines in and out of the station, transformers, links, circuit breakers, etc. The various equipment are colour coded as per their operating voltage. A number of operations can be performed to obtain more information by clicking the mouse pointer on various points on the screen.

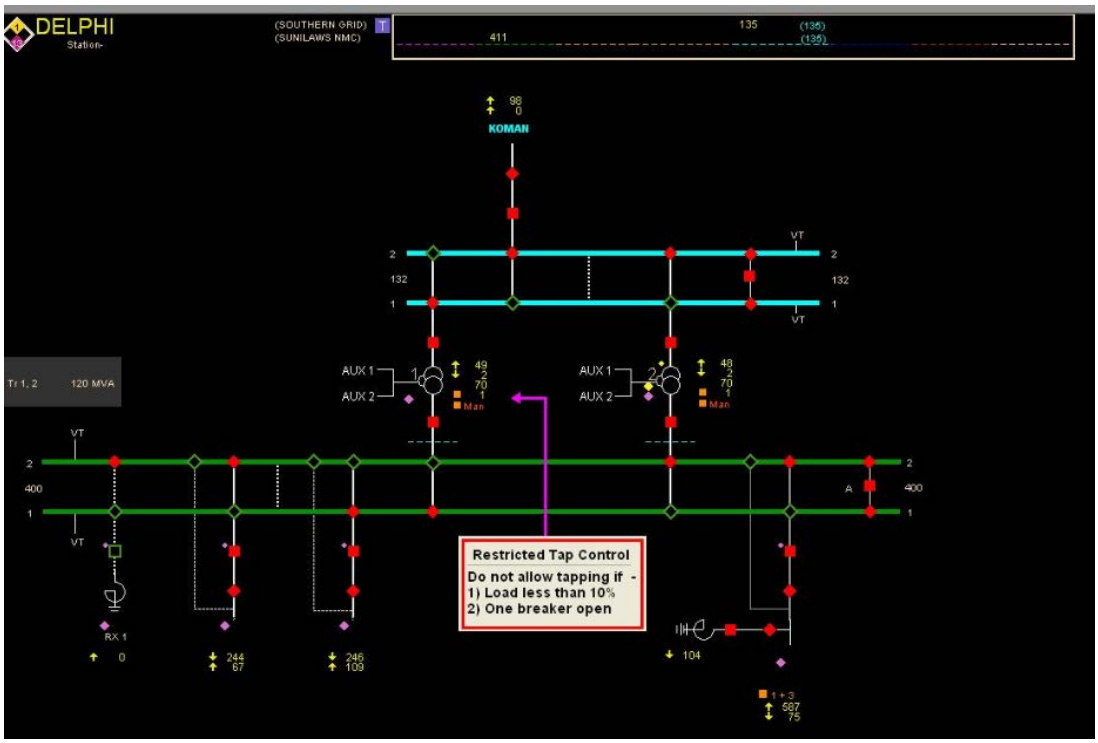
Voltage level summary screen.

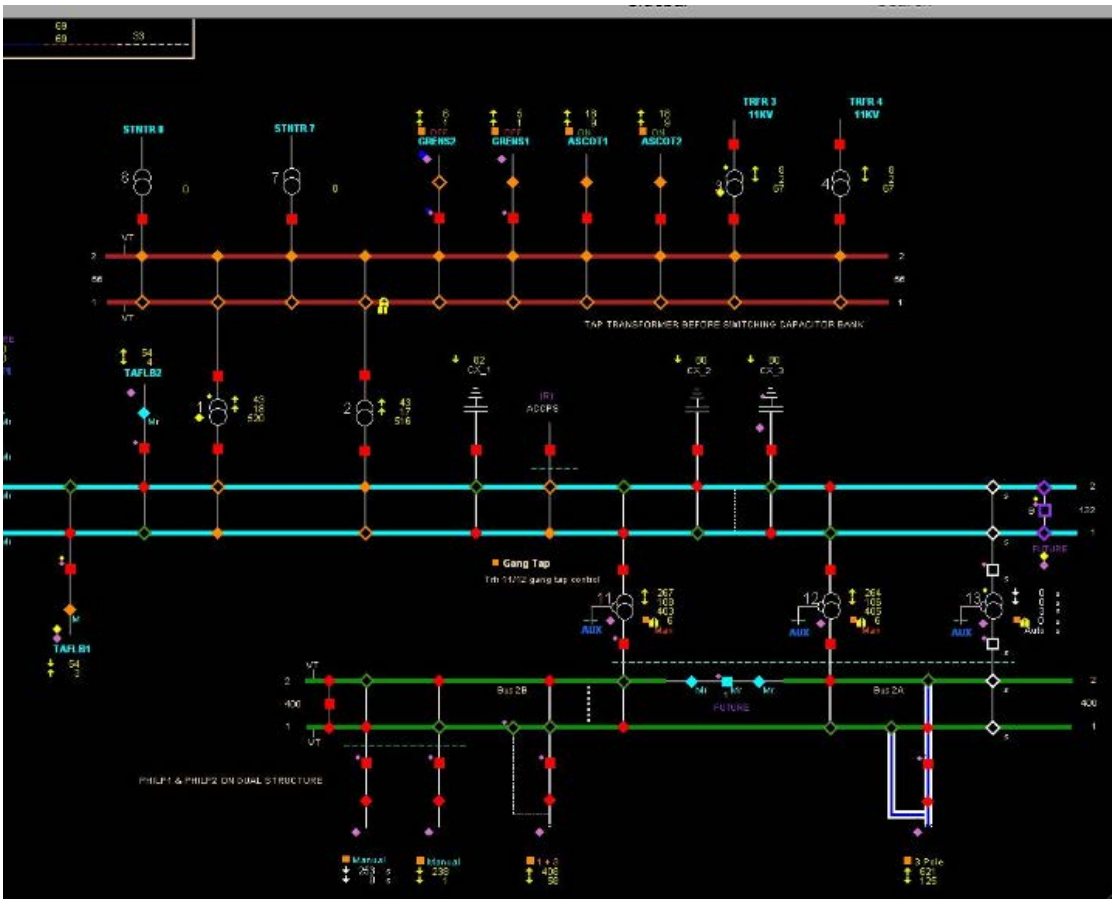
This shows a list of numbers in columns, which represent the voltages at all the bus bars in the network. These are arranged in regions as per the different regions of the transmission grit in the country. The different transmission voltages are depicted in colours as above. When preset low and high voltage limits are exceeded the colours of the numbers change which assists the controllers in identifying the discrepancies. Various mouse operations reveal different information required by the controller.

As this information is sensitive the level of detail will be limited to what is presented here.

## TEMSE SCREENS

### TEMSE Substation layout screen




STNTR 8
STNTR 7
GRENS2
GRENS1
ASCOT1
ASCOT2
TRFR 3 11KV
TRFR 4 11KV
TAP TRANSFORMER BEFORE SWITCHING CAPACITOR BANK
TAFLB2
TAFLB1
Gang Tap
AUX
Bus 2B
Bus 2A
FUTURE
PHILP1 & PHILP2 ON DUAL STRUCTURE

## TEMSE Voltage summary page

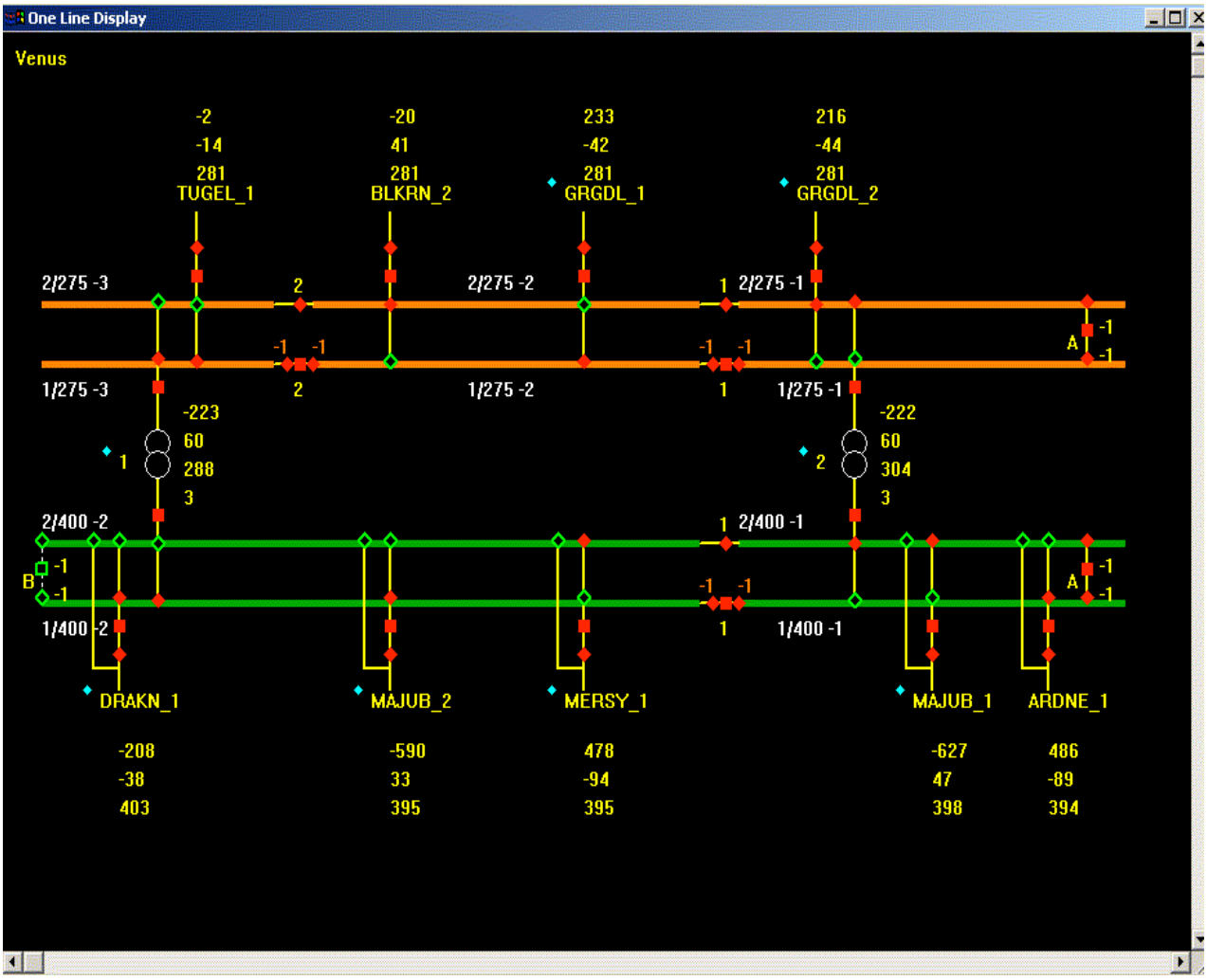


## ENCOR SCREENS

**ENCOR Voltage display screen**: This is from a photograph of what the voltage display screen looked like as there are no references off a computer at this stage.



**ENCOR Substation Layout screen**



# APPENDIX D

In this section the full results from the controllers responses to the interview questions are presented.

## D.1 Written Feedback

The controllers were asked to write down what happened during the exercise on the simulator. This was done without any further explanation from the interviewer. Copies of the scanned written responses are captured and stored, and have been included in Appendix A, together with the controller sketches of the network, some technical information has been deleted due to security reasons. This information does not have direct bearing on the research questions but only serves to provide a starting point for the research which followed. Below is an appraisal with respect to what was emphasised and the sequence of what was written in terms of:

What happened,

What they did,

Which came first, and

Any mention of internal processing (thoughts, feelings, sensations) if any.

The idea is that descriptions of what happened are furthest from descriptions of tacit experiences, descriptions of what the controller did are a bit closer to the tacit domain while mention of thoughts feelings etc. are closer still.

The written descriptions of the events on the simulator were described in various ways. On the one extreme one controller just wrote down three points while the longest description was about two sparsely covered pages. The majority did not make any mention of thinking or any other internal phenomenon. First we have the information summarised from each controller’s writing:

Table D.1. A: Controllers written descriptions of the simulator events.

| Controller | Style of writing | Sequence used |
|---|---|---|
| C1 | 20 points, one page of writing | What happened<br>What he did<br>Internal processing (thoughts)<br>What happened |
| C2 | Continuous prose ... six sentences, about half a page | What happened<br>Internal processing (thoughts)<br>What he did<br>What happened |
| C3 | Three lines only | What happened |
| C4 | Three points, about half a page only | What he did |
| C5 | Four statements no detail | What happened |
| C6 | Seven points /lines, about a third of a page | What he did<br>What happened |
| C7 | Two points, with ten lines shorthand style | What happened<br>What he did |
| C8 | One and a half pages of information, twelve points, with about five or more lines of writing describing each one. | What happened<br>What she did<br>Internal processing (thoughts) |
| C9 | About two pages of writing, 9 points with detail on each | What he did<br>What happened |
| C10 | Point form, three points and three comments underneath | What he did<br>What happened |
| C11 | Eleven points, about a page of writing | What happened<br>What he did |
| C12 | Six points with detail in each, one page of writing | Internal processing (thoughts)<br>What he did with alternatives<br>What happened |
| C13 | Seventeen points, one page of writing | What he did<br>Internal processing (thoughts, heard)<br>What happened<br>What he did |
| C14 | Seven points with some | What happened |

| | | |
|---|---|---|
| | detail 60 % of a page | What he did |

### D.1.1 Analysis

In terms of the research question requirement being the investigation of the tacit domain, the five styles of reporting shown above are classified from the least tacit to the most tacit. The more the information is about self, the closer it is to the tacit dimension, in the following order:

Table D.1.1.A: Findings from the controllers' written descriptions of the simulator events.

| | | |
|---|---|---|
| What Happened | 2/14 = 14.3% | Total with no mention of personal reference 14.3% |
| What Happened / What they Did | 6/14 = 42.8% | Total with some personal reference 85.6% |
| What they Did / What Happened | 5/14 = 35.7% | |
| What they Did | 1/14 = 7.1% | |
| **Mention of Internal Processing** | 5/14 = 35.7% | **Overall total** with explicit awareness of internal experience 35.7% |

There was no mention of true tacit phenomena, but 35% of the participants did allude to mental aspects of their experience in their written reporting of what happened. This was done without any prompting and therefore can be regarded as an inherent tendency for these participants as the writing was done without any intervention from the interviewer. As there was no information in the instruction to elicit references to the tacit domain the results are not surprising.

The two participants who did not make any reference to self (wrote only about what happened) in their account are a minority in this group.

There may by numerous reasons for this, but it turned out that of these two, one gave almost no information at all about what was going on in his mind when interviewed, and the other had very simple mental imagery to report.

The writing down of what happened was the first step in the interviewing process and it serves as a reference of what may be the normal focus of each individual in the context of their work at the NCC. Most of the participants took some time before they could report on the tacit aspects of their experience during the interview. The most common response, when asked about what was going on in their mind, was to report what they did or what they noticed about the network. This speaks to the challenge the interviewer had to overcome in order to elicit tacit phenomena information. It also shows that the area of investigation was totally unfamiliar to the controllers as well.

In the next section we will find out what the controllers felt during the exercise.

## D.2 Emotions

In this section the emotional components of the controllers' experience during the simulator exercise are summarised and analysed.

**The part of the Research Question asked here was (in bold):**

> **What are the** tacit mental structures, content and **emotions,** which arise within the minds of the controllers at the NCC, **as they work with the newly implemented TEMSE Windows based computer interface**?

Emotions and their various components are at the borderline between the tacit and conscious experience. They are an important indicator that there is internal processing below awareness. Unless there is some inner conscious or subconscious reference (Ekman & Davidson 1994) to define the current situation as having some significance there would be no response or emotions to go with it (Shalif 1987; Anderson 2002;

Pinker 1999). In this respect therefore the information presented below takes us another step closer to the tacit dimension. The reports given by the controllers are classified as follows:

- A summary of the key emotion words reported by the controllers as they recollected them after the simulator exercise is tabulated.

- Secondly, these emotion words were compared with the emotions the controllers reported having while dealing with a contingency in the control room, when they were all alone as they were in the simulator (Form 2 from the Methods chapter was used for this, Appendix B). Then the correlation of the two was Confirmed or Not confirmed, and comments are made where there is a difference.

Overall the emotions reported by the controllers during the interview were confirmed to correspond to what they experience inside the control room. They were given three copies of the 15 basic emotion bi-poles (Shalif 1987) and were asked to complete them in response to the three questions below.

**The three Questions** to which the controllers were asked to respond to, in writing, using the forms with the 15 emotion bi-poles which were shown in the methods chapter, were, "How do you feel when …":

1. **Working in the control room under quiet late night conditions?**
2. **Working in the control room when there is a contingency, which you face alone?**
3. **Working in the control room during a contingency, which you face with support from other controllers?**

The second question is about how they feel when faced with a contingency inside the control room, which they have to face alone. This is very close to what they had to face in the simulator exercise, where the contingencies were presented to them alone. In this way the emotions referred to on paper and the ones mentioned verbally should compare

closely with each other if the two experiences are similar. In order to avoid pre-empting their responses, the controllers were not asked directly if their emotions in the control room and the simulator correlated. The three scenarios presented to them were left for them to interpret. The forms with the second question responses from the controllers are captured in Appendix B.

### D.2.1 Controller Statements

First, the relevant sections of the controllers' statements from the interview transcripts are presented below.

## C1.

C1: In this instance I did expect it so the feeling is mild, it's different in the control room but once it happens it's the same.

1st trip, I expected it, **no panic**

2nd trip, a bit of caution (at first)… then I thought, "have I done something wrong?", this **takes it up (the feeling of panic) exponentially.**

3rd trip, same as with the 2nd.

## C2.

Int: How do you feel when the alarms go off?

C2: Not so bad I am expecting it, so it's **mild.**

Int: Even though the feeling wasn't very strong what was it?

C2: **Urgency**

Int: Where do you feel the feeling of urgency?

C2: A little bit in my stomach but very mild, very mild

…finally load shedding, the step you don't want to take …I feel **resistance** from myself **very strong** feeling …9/10 feeling

Int: Even in the simulator

C2: People lose the system because they don't want to shed load.

When I'm in sync with reality it's easy to make the decision to load shed…now I'm out of touch so its dangerous.

## C3.

Did not say much about how he felt. The questionnaire at the end showed **mild fear** but I'm not sure, as he did not say much.

## C4.

Int: While looking at these numbers and all is good, how do you feel?

C4: Good … I go from region to region

Int: Where do you feel this feeling when everything is good?

C4: I feel **relaxed** in my body, and a **light** feeling.

its just a feeling over here, (up to the right) it feels that your mind is **alert**…it's a mental thing…not tension just something to deal with …

Int: Your hands are telling us something … ?

C4: Yes it means I am **not comfortable** until I do something to fix the situation so that I can live with the outcome…

Int: What is your internal response to these events?

C4: I don't want to say **"in the zone"** but sort of…

Time disappeared 14 minutes seemed like 2 minutes

If I go and finish the operations in my mind it all feels good and the **"unfinished business" feeling** goes away … and I liked to see that I was so comfortable working by watching the video of me working on the simulator, and to see how well I did.

## C5.

I was thinking that I need to shed shed, shed, load

I thought shed, shed, shed, shed, … a voice.

Then all the voltages went, … then I took long to think … I was looking at those voltages on the screens …

The little voice, … that is why I went to Marathon (substation)… I wanted to say to Jan (simulator trainer), **stop I can't do it … I lost concentration I thought, this is too much**, … then another voice said, you can try this … shed load … I wasn't sure if I should listen to it.

## C6.

C6: The first incident was ok… I felt reasonable… with the 2$^{nd}$ the transformers were overloading …I should have concentrated more on the transformers … it almost collapsed the voltage… I thought where do I go now, you can see my head is moving on

the video… I am looking… if you are looking at one station only you don't see what is happening further,… one voice says **"I can't do this",…** another part says **"do it, be calm** you can do it" …there are two voices at first… another "check this transformer over there"… the calm voice comes from the back (points behind his head), the worried voices are all around my head, the calm one is trying to push the other away… the images are about what someone may say to you "why aren't you doing something etc." and then there is a third voice "do you know what to do?" … Then I have to decide how to approach this, the calm voice in the back of my head allows me to just relax move on to the next step… there are no images, just in the beginning there was one, then just voices…then I listen to the guy at the back the calm one… not listening to the others, I calm down, relax, and analyze it and go from there … with all the commotion it **breaks you up**…I go and look on the screen to restore the mental image and go from there…the level of detail is the same as the screen then I feel more relaxed when broken up I feel **scared** its trying to pull you away from the work …then you are no longer **fidgeting**…

## C7.

Int: How do you feel about the incidents?

C7: It feels like being at the starting line of a race, and you hear the starting gun go off … it makes the mind want to operate at a higher level… something that is triggering you **to operate faster**…

Int: What's it like to see yourself working?

C7: I'm quite a calm person but a lot is going on inside …you won't see that on the outside… I may look relaxed but inside I'm thinking about the voltages, I'm trying to be ahead of the contingency, to be ahead of what may happen

I imagined a voltage dive … had a **tense feeling** but relaxed as I saw it was not as bad.

## C8.

Int: If you do that **now** how do you feel about it?

C8: It makes me **feel much more relaxed**, because I can see all the sections in colours depicting the different networks, I don't have to flip back and forth between the different networks (shows with her hands).

## C9.

C9: Your state of alertness makes a difference on what you can do…

C9: It's easy to cope with one contingency

Int: Hey if there are no risks involved, you know what to do! Ideas keep coming its like taking off a hand brake, when there's no fear you have expertise can you see that!?

C9: Yes! Laughs

Int: Notice how smoothly you do all this, but if I say to you "press the wrong button you're fired" it all goes out the window. So its not about ability, it's about "provided that", if I keep you frightened you're paralyzed … the thing is you think of yourself "I cant do this" and that's the problem …but you can and you have shown it!

C9: **Ya, that is actually quite scary!! I understand.**

## C10.

C10: I look at the substation it should be (gives the values for the voltages) … I saw 280 kV which is too high and same for the caps they were not on their normal setting. It shouldn't be like that made me **uncomfortable** …

C10: I see that we are sitting with … (kV), this its close to collapse point, **it feels its close … right next to you … you want to keep as far as possible from it** …

Int: What happened next?

C10: The network and I "we have a feeling for each other now" I just want to keep away from the "collapse point"

the network **going down hill**, to the "black hole" … **I feel uncomfortable** …it **became worse and worse**, you want to give up, in my head **I got that loser feeling**, … even though you **want to give up** you can't give up, … there is no way you can ignore it, **you have to fight it**…

## C11.

I was **tangled**

I got **stuck** with this incongruence

… so I got stuck

## C12.

**I feel nervous inside… I feel I have to do something …**

Int: If you had to choose font size which one would you prefer?

C12: I prefer to use the old larger ones because I can see them better my eyes are ok but it might eliminate **strain**, as I was peering at the screen in the beginning of the exercise…

when I look at ENCOR I know where I am, and that feels good… I **feel light** when I see ENCOR and **heavy** when I see TEMSE.

I feel **nervous inside**… I feel I have to do something …

## C13.

when the second alarm came **I felt more scared**…

… I thought the whole country is gone, oh! ... Total collapse … **I got strong feelings** inside, with every alarm that comes I get a certain feeling.

I condition myself to prepare for the worst thing when I wake up and know I have to go to work, then I have to be prepared about, what if I make a big mistake, and something terrible goes wrong.

Even here in the simulator, **I felt it after the second alarm**…

## C14.

Int: How did you feel when you saw those voltages?

C14: A sense of **urgency…**

Int: What happens next?

C14: There is **some fear**, some rush of something, like adrenaline, in my (shows abdomen) … this feeling clouds everything at first…those colours were really **scaring me**, the 275 kV voltage which looks blue when it is low … the feeling has **high intensity** if there's a lot of blue, one blue value is fine

In the simulator room you are limited in what you can do … inside the control room there is more I can do, and faster, the delays here **frustrate me**… Inside the control room the process if very efficient, and very quick, … if I don't have to speak to any one I just go and do it, … inside I am like part of the system, I do it automatically … I interact with the system…

### D.2.2 Summary

Table D.2.2.A: Findings summary from the emotions section.

| **Controller** | **Emotions / Feelings Information from the simulator exercise transcripts** | **Comparison with control room questionnaire** |
|---|---|---|
| C1 | Panic | Confirmed |
| C2 | Urgency, resistance from myself very strong | Confirmed |
| C3 | Mild fear | Confirmed |
| C4 | Light, alert, not comfortable, “in the zone”, “unfinished business” feeling | Confirmed |
| C5 | Can’t do it, lost concentration, this is too much | Not -Confirmed (1) |
| C6 | I can’t do this /do it be calm (conflict), scared, breaks you up, fidgeting | Confirmed |
| C7 | Operate faster, tense feeling | Confirmed |
| C8 | Afterwards “Now I feel much more relaxed” (before scared / tense) | Confirmed |
| C9 | quite scary!! | Confirmed |
| C10 | Uncomfortable, going down hill, the “black hole”, uncomfortable, worse and worse, want to give up, in my head I got that loser feeling, … want to give up you can’t give up, have to fight it | Confirmed |
| C11 | Tangled, stuck | Confirmed (2) |
| C12 | Nervous inside, I feel I have to do something, heavy, strain | Confirmed |
| C13 | More scared, strong feelings | Confirmed |
| C14 | Urgency, some fear, high intensity, frustrate me | Confirmed (3) |

Comments:

1. In the form this controller indicates that she feels much better when a contingency that she has to face alone takes place. This is not what happened in the simulator … Further investigation may be required with respect to how she relates to the people in her shift who may have an inhibiting influence on her and / or for other hidden factors.
2. This controller reported that he wanted to further his prospects as soon as possible and so for them to be on night shift under quiet conditions was a frustration. When a contingency came he felt an increase in interest and pride and a desire to perform. As a result working under contingency conditions had an invigorating effect, however *when things did not work out* he felt stuck.

3. This controller reported that inside the control room he felt at one with the equipment and much more at ease with working under contingencies whereas in the simulator the various delays caused the frustration. The discrepancy between the verbal and written reports can be accounted for in this way.

### D.2.3 Analysis

92.8% (13 / 14) of the controllers produced written evidence that what they experienced emotionally in the simulator was very much the same as what goes on in the control room. Of the 14 controllers, ones verbal and written comments were not similar at all, and of the other thirteen two had discrepancies. These last two however, corroborated their written reports by other verbal statements, which they made during the interviews, which allow for the “Confirmed with comments”, outcome. From all the above, it could be said that the same tacit forces may be at play in both situations. In other words the emotions, over which the controllers have no conscious control, which they experienced in the simulator are very similar to what they feel inside the control room under similar conditions.

The words used to describe their experience during the simulator exercise were:
Panic, urgency, very strong resistance from myself, mild fear, “in the zone”, light, alert, not comfortable, “unfinished business” feeling, this is too much, conflict, scared, breaks you up, fidgeting, tense feeling, scared / tense, uncomfortable, going down hill to the “black hole”, worse and worse, want to give up, that loser feeling, want to give up you can’t give up, you have to fight it, quite scary, tangled, stuck, nervous inside, I feel I have to do something, heavy, strain, more scared, strong feelings, urgency, some fear, high intensity, frustration.
And afterwards: “Now I feel much more relaxed”

Considering that the emotions and feelings described above are quite intense, even though the work carried out was in the simulator, one can only imagine the consequences of having to live with such emotions and sensations inside the control room given that

there is very little discussion about them. I believe that this aspect of the controllers' experience should be studied further as there have been instances of severe stress symptoms demonstrated in the past.

In the following section we will find out what was the tacit visual and auditory experiences of the controllers, as they worked on the simulator. This is the most important section of this chapter.

## D.3 Tacit Content

In this section, the findings that pertain to the tacit content of the controllers' experience are summarised. The sketches, which show the level of detail of the controllers' mental images are included in Appendix A. The results are then summarised in tables followed by an analysis. This analysis will be used in the conclusion chapter to create a cohesive narrative of the findings, together with the analyses from the other sections of the results chapter.

**The part of the Research Question addressed here was (in bold):**

> **What are the tacit mental** structures, **content** and emotions, **which arise within the minds of the controllers at the NCC, as they work with the newly implemented TEMSE Windows based computer interface?**

The verbal interviews began after the exercise on the simulator was completed, and the controllers had given a written account of what happened,.
The information provided by the controllers about the tacit content of their experience, was extracted, simplified, and tabulated. Then the information was analysed to identify the following points:

- Were there mental images?
- Were they in colour, or black and white?

- Were they simpler than the images on the computer displays or as complex, and was there any other mental imagery, like maps etc.?
- Did they resemble the ENCOR or TEMSE displays?
- Were these images used to “navigate” the contingencies?
- Was there a prominent inner voice (auditory) component to the tacit experience?
- How many elements (lines, bus-bars, etc.) were included in the mental images as presented in the sketches the controllers produced?

Most of the participants took some time before they could report on the tacit aspects of their experience, during these interviews. The most common initial response, when asked about what was going on in their mind, was to report what they did or what they noticed about the network. This was quite a challenge for the interviewer, which had to be overcome in order to elicit tacit phenomena information. In this respect, other non-verbal queues from the controllers, like hand movements used to indicate imaginary lines and areas of the network, eye movements and gazing, or actual statements alluding to the existence of mental references, were very useful in order to elicit the elusive tacit representations.

When the controllers became consciously aware of the spontaneous arising of their internal representations during the exercise, their reports became quite lucid and easy. In fact, during instances where the interviewer made detailed enquiries about how things were represented in their mind, most were very confident in presenting all the detail required without hesitation. However in order not to install images or other experiences in the minds of the controllers the interviewer did not insist or explicitly ask them to “see” anything. Due to this constraint some controllers did not produce sketches because the way the conversation went did not provide the opportunity to explicitly ask for one without pre-empting its existence. For instance in one instance where one controller insisted that he had no internal representations the matter was left to rest, as there was no point in asking for sketches of something he said did not exist. Ironically, many of the statements that the same individual made could only have been made if he indeed had

internal images describing the network. The whole point of the interview style was to be as non-invasive as possible.

Key to the success of this process was to first direct each individual's attention to felt experiences, emotions and their somatic location, as they are quite accessible for most, then to the visual and auditory aspects, and away from descriptions of actions performed and network information. Another key factor was to provide each participant with permission to take as much time as required in order to shift focus on the tacit domain, which then became quite vivid. The time element is a very important factor when eliciting tacit content and it is important to allow as much time as each person requires to describe the complex visual and auditory content in their mind. The expression "one picture is worth a thousand words" is not an exaggeration when it comes to tacit detail. As one controller eloquently put it, "You don't think about it, all the things that go on, for every one step (you take), you have ten other things going on in your mind, you could write a book …"

### D.3.1 Controllers' Tacit Content Descriptions

Table D.3.1.A: Controllers tacit content descriptions

| Controller | Information (Tacit Content) | Comments |
|---|---|---|
| C1 | I saw an image of Matimba and Witkop with two lines joining them (sketch I). Two blocks, grey against a white background. The image is like TEMSE. ENCOR would have been larger.<br>With the 2nd incident this is what I saw (sketch II) two horizontal lines with three vertical lines of which one on the right is fuzzy grey on white (TEMSE). I then saw the two transformers in red as they were overloaded, … (he heard / thought in his mind) the steps he followed to respond to the problem.<br>1st and 2nd sharp, 3rd fuzzy. …like seeing it through a piece of plastic.<br>C1: Yes, more stress more fuzzy.<br>(Single line diagrams with 3 to 15 lines) | Simple images appear as per contingency B&W and colour. Inner voice. TEMSE. Images are used to navigate. Single line diagrams with 3 to 15 lines. |

| | | |
|---|---|---|
| C2 | The image jumped out … I see the two areas as a single line diagram…(sketch I) I see … this is the one area and this is the other area, … yellow …I see they come out of the wood work, pssst…they are both yellow, … the network generally is white<br>It's a picture like neither ENCOR or TEMSE<br>C2: You just zoom in where you need, … The picture is more simple, but it's easy to work<br>The mind image is about 5 to 10 % of what is on the screen<br>(Single line diagram with about 22 lines) | Simple images appeared in colour and B&W for each contingency. Not TEMSE or ENCOR. Images are used to navigate. Single line diagram with about 22 lines. |
| C3 | You think more rapidly. I do not see images I look on the screen … It tells you … if you go to a station there it's got in-feeds and out-feeds, this tells you where to go next. It's easier in a region, which is not so interconnected … when you think of Natal you have two feeders, then it goes from station to station… (gestures with right hand from bottom upward indicating stations at four intervals .) I don't see stations … if you look at the screen … its easier<br>Yes like in Natal … (lists a few s/stations) or in the Western Cape (lists some more) … I'm not the kind of person, who forms a picture in my mind if you talk about a car, yes, that's a picture but not the system… I see lines there on the screen.<br>There is more detail on the screen than in my mind, TEMSE and ENCOR are the same … I get information from the screen … I haven't got imagination…in Natal it's a straight road, here its zigzag (moves his right hand).<br>I know the basic layout and then I use the screen to go from there. Now its TEMSE pictures<br>(No Sketch ….) | Thinking speeds up. Said there were no images but kept on referring to mental imagery with less detail than the screens. Images are used to navigate together with screens. TEMSE? No sketch. |
| C4 | I had a visual of Matimba, Matraco, etc. it's all linked… (Points to the right hand side and upward above his head with his hands) …I see the low voltages,<br>It's like TEMSE, ENCOR is gone now …the pictures look like TEMSE… the pictures went further back to right when I confirmed what was in my mind… In my mind it goes blue for low voltages and red for high … there is still a picture in my mind of the two lines (up to | Images of voltage numbers as well as schematics, which become simple as |

| | | |
|---|---|---|
| | his right).<br>I'm talking a lot to myself here … I am talking to myself all the time, do this, do this.<br>First I saw mental pictures without referring to the screen and the pictures are the same as the ones on the screen…<br>There are ten things going on inside, for every one thing you do,… no no wait, … you know when the trip happened you tend to black out those things that do not make sense to you, you take them out, … the areas of impact get highlighted you check from Witkop down to Matrako, (gestures with his hands in a sweeping motion). Under normal conditions you see the system as it is, but it doesn't bother you … but when it hits, … its you take that picture … its amazing, now as I think of it, … this is what happened the whole time, but I didn't say it, Matimba came out, … the 275 and all that (gestures with his hands from right to left in front of him and up to the left),… it's a simple picture, but just the backbone (see picture sketch) it shows how its linked back… this is a simple image of what I saw when there was a problem… and it was highlighted the whole time… that is how you know where to go the whole time! Where you can improve your voltages …<br>(Single line diagram with 11 lines) | contingencies unfold, they move around as things change.<br>TEMSE.<br>Internal dialogue.<br>Images are used to navigate.<br><br>Single line diagram with 11 lines |
| C5 | The picture was Marenski and Arnot … in colour… like the TEMSE pictures…I start at Central…Free State, Western Cape, Eastern Cape, Natal, … it's a colour picture like TEMSE … I do not remember the ENCOR picture, is gone far far behind…<br>It is simpler when everything is fine … it's more when there is a contingency incident … more detail … I look deeper I have to analyse … I thought shed shed shed shed, … a voice.<br>I do mental calculations in my mind.<br>Arnot feeding Marenski …. That picture was not complicated, it's in colour, it doesn't have all the detail (draws sketch) A picture of the voltages higher then say 260 kV, or higher, (draws an arrow at Marathon)<br>(Single line diagram with 4 lines) | Images appeared in colour like TEMSE then they became simple with the advent of the contingency.<br>Inner voice and mental calculations.<br>Images are used to navigate.<br>Single line diagram with 4 lines |
| C6 | The pictures in my mind were two, I saw Arnot as well, … its still in my mind even though I am looking at the screen.. It's just like a puzzle … one voice says "I can't | Many images appeared in front and |

| | | |
|---|---|---|
| | do this",… another part says "do it, be calm you can do it" … another "check this transformer over there"… the calm voice comes from the back (points behind his head), the worried voices are all around my head, the calm one is trying to push the other away… the images are about what someone may say to you "why aren't you doing something etc." and then there is a third voice "do you know what to do?" … the calm voice in the back of my head allows me to just relax move on to the next step… there are no images, just in the beginning there was one, then just voices…then I listen to the guy at the back the calm one… not listening to the others, I calm down, relax, and analyze it and go from there ..<br>I have a mental idea it brings that picture in my mind exactly like that above to the left in front of me in my mind I have the picture while looking at the volt page all numbers… it's a small picture same colours I also have an image of what the place looks like… the picture of the normal network starts to break up when something goes wrong like a TV picture that goes fuzzy …with all the commotion it breaks you up…I go and look on the screen to restore the mental image and go from there…the level of detail is the same as the screen then I feel more relaxed when broken up I feel scared its trying to pull you away from the work …then you are no longer fidgeting…<br>… network as a whole it's too big …when contingency I see behind my head stations feeding into it this is where you go first …in this instance no big picture because it's isolated. … the big picture did not get activated…<br>TEMSE<br>No sketch… | behind his head.<br>Diagrams and actual images of the areas.<br>Internal dialogue with many voices.<br>When things go wrong the image goes fuzzy, as emotions get stronger.<br>Looks to the screen to restore mental image.<br>TEMSE.<br>Images are used to navigate.<br>No sketch. |
| C7 | I see a picture, a page around the Matimba area, almost similar to the screen, and the surrounding area I imagined a voltage dive … It's that blue picture which highlights when the voltages go low … no schematics just a voltage number (against a blue background)… I went to the screen to look … when the second thing occurred I went to Arnot…I had an orange background with Arnot on it, surprising it wasn't blue… then I thought of Mozal, … I could see that schematic diagram (sketch on paper) in the mind, this is what I saw, … It's in orange colour, it's the 275 orange…<br>Yes this what I see under normal conditions and under a relaxed state … the same picture came up during the contingency… I started scanning in my mind, I have a | Images appeared in colour.<br>Used images to navigate.<br>TEMSE.<br>6 line diagram. |

| | | |
|---|---|---|
| | schematic diagram what feeders can be coming out, its blue for 132 kV, I see Marathon (substation) blue as well…<br>C7: In my mind I see an overview, its blue, it just triggers me to look further, it's a simplified drawing to help me know where to go and look…<br>(Single line diagram with 6 lines) | |
| C8 | I lump it up like islands… it's interconnected … and the power flows from Arnot … I see the geographical map, they do not look like TEMSE or ENCOR …<br>…the geographical map is the most important, together with the computer screen, in my mind I see the islands but not interconnected … the connections are there but I do not see them in my mind. First Matimba then Arnot. I don't see lines I see a big pool … an amorphous shape green colour,<br>Arnot was already orange, …it's a hidden picture not clearly visible … its behind the other pictures in my mind when I look at it I see another pool supplying Kamden …when I notice it and focus on it, I can see it … in my mind I know there is a connection … Yes the connection is behind the pictures.<br>C8: Matrako would have to come forward, together with Arnot and Matimba then I could see all of them in front of me, and this would allow me to make decisions based on what I see I didn't do that.<br>The geographical picture is important, that would look like one big picture colour coded. The islands would be interconnected all in colours it makes me feel much more relaxed, because I can see all the sections in colours depicting the different networks, I don't have to flip back and forth between the different networks (shows with her hands). I know that even though this is interconnected I could see this is the load zone, this is this area, this is that area etc.<br>Int: If you had this technique when you did the exercise, would it be useful<br>8: Yes I would see this geographical picture, … then you pluck the numbers and the picture is full, as things start to happen you see the load flows, … everything, … the power flowing there, you putting the constraints etc., it would be much much better!<br>C8: Its what I saw, … the different colours …the blue colour on the voltage side … the colour was the first thing that jumped out …. it's busy flashing … I thought reduce load … | Simple pictures and geographical map with islands. Colour. Used to navigate. Not TEMSE or ENCOR. Sketch with 3 elements. |

| | | |
|---|---|---|
| | When it's normal it's just there, everything is smooth, when things are abnormal it looks like its doing this (pulsates her hands back and forth) … draws my attention the colour changes to orange and red… see less of the rest and more of the one…the detail you don't see everything but bigger…I saw the Marenski line flashing (see sketch) this became a bigger thing … and all these little things in the Arnot ring disappeared to the side when the transformers tripped<br>I had to go in my mind to check what is wrong, I have to go see what is going on … with the alarm I look on the screens, then this picture became bigger (sketch) … I see what's going on when all is fine with the alarm all the big stuff disappears and smaller things become clear… the regions … interconnected, … then when new alarms come you look at the screen again and new pictures become big.<br>("Blob" diagram with 3 elements) | |
| C9 | I see a picture of the network …its automatic …I have no idea how I do it… I look at the voltage page, I like to confirm what I'm thinking… the image is similar to what's on the screen, more like TEMSE now than ENCOR … I'm used to seeing this (TEMSE). If you look at a screen and there's something wrong, it will tell you by going red …when I'm relaxed the images of the different regions are easy to see…<br>C9: Pauses for a while, then starts gesturing with his hands above his head and with eyes half closed he starts describing, … there are three layers of imagery depending on what is going on. You know, in that substation there's load, transformers, etc …three layers.<br>(No sketch) | Simple picture, TEMSE, colour. Used to navigate. No Sketch |
| C10 | I see the whole lowveld network … The mental picture is like a road map … we are so trained in these colours … many pieces at a time …if I see low voltages I know the load is high … I say "if I don't do something there" I see the whole Arnot picture …same distance as the screen and the same colour …as when it's normal… the picture in my mind is what you expect to see, then you look at the screens and compare… not every fine detail. When the Arnot transformer tripped you tend to have a focus point … I will see this in my head, this is much prominent, if you close a breaker you expect it to go from green to red. Yes the pictures are similar, some things become more prominent and others fade … in this case I was just waiting for the worse, | Simple pictures, colour, TEMSE and ENCOR, used to navigate. Inner voice. No sketch. |

| | | |
|---|---|---|
| | (No sketch) | |
| C11 | The colour picture in my mind is like a TEMSE picture, it's the same … The mental picture is 80% the same as the screen picture …it takes a few seconds to make the adjustment from mind to screen though… on the mental image I would see 276 kV instead of 273 kV, the same colours like TEMSE.<br>I have made up a mental image by regrouping the equipment, so that my mind and the screen are not the same…. I can see the power flow … I have a picture of a normal state network, the picture is bigger, big, double the normal screen size, the colours are correct according to the TEMSE style … still there are old pictures in my mind which do not match the new upgraded network with new lines etc. … (He shows with the hands a bigger picture about a meter and a bit in front of him like the screen but much bigger…)<br>Now I see it in detail, it took about two years to get the images. I see better in colours … now I have it… Those pictures are slightly different to the current TEMSE, as the network has changed since 1999 … from 2002 I had it all mapped out in my mind…<br>When you say Arnot I get Mozal with it… the Mozal line picture comes together with Arnot … something was "telling me" like a voice, an inner prompt, shed load, but I didn't do it … "I knew" I pictured it and that did not match the screen … the image was just this section (points to the screen then draws a sketch)…this is what I saw in my mind to compare to the screen image. I see it as black lines on white background to see what to do…<br>(Single line diagram with 11 lines) | Complex pictures, colour, and simple B&W pictures. TEMSE and ENCOR. Used to navigate. Diagram with 11 lines |
| C12 | I see the caps at Witkop, Marenski, and Foskor in my mind … I see a schematic … I see bigger thicker lines, bolder numbers, in colour … a full version as in TEMSE … I see them and I question myself what am I to clear … I see Foskor as a schematic…I don't see the bus bars because my mind is on the cap… the cap picture it will be a little block with two lines, whitish, … the block would be blue and It just came up by itself, it just popped up … the quality of the picture is closer to ENCOR … TEMSE is small and cluttered, … then Matrako struck me, … a picture, I see the Matrako network, the top network of Matrako, … this is the area I see in my mind, and another area is Maputo, because I have caps at Maputo… they are all linked together, … I | Simple mental images, colour, inner voice, ENCOR, and TEMSE. Use to navigate. Diagram with 3 elements. |

| | | |
|---|---|---|
| | see that picture when conditions are normal and it is the same as when things go wrong …<br>I see Mozal and the northern region with a worse problem, … I had in my mind that there could be problems in other areas, like the Western Cape… I heard the words, I better go and check, … I saw a part of the region, just numbers of voltages, a lot of them in a straight line, purple blue … then I heard a voice, this is not going to happen… … then I saw a picture of the pot (smelter) and the breakers in blue (sketch)<br>This is more like TEMSE …<br>(Single line diagram with 3 elements) | |
| C13 | I see pictures …single line diagrams (shows with his hands in front on right)… I see the physical station the building etc., and then I saw the Marenski sub-station the actual station, I see Arnot as a place … then something's wrong in the network … I started imagining the normal voltages like on the computer screens … I see a geographical picture (describes on a map with the network on it)… I think of the healthy voltages … I see numbers of the voltage at the bus-bar, one line image of the bus-bar … The bus-bar is blue if it's 132kV and green if it's 400 kV … I see the lines blink when overloaded and the bus-bars steady …<br>… I thought, can I ask for verification? … I saw the two lines were out, in my mind… I see the voltage collapse, the numbers going down very low … 110 kV, … the picture in my mind is the same (format) as the screen, … the picture is far (points backward behind his head) the same distance as the computer screen, but behind me… I first see the whole network then the sections, one by one … first Midas then I didn't know how to relate it to Apollo and Arnot… the pictures in my mind stay the same, … I did not see the transformers overloading but I heard the alarm and checked and they were overloading and thought, I may have done something … now I'm seeing the source, Matimba flashing, the voltage going down seeing the generators at zero and the network going down … I see it as a map which is useful to make decisions, (he shows with his hands top to bottom in front of his face) … the picture is A4 in size and behind me some distance …<br>I see the picture of Arnot station as a single bus-bar, then Matimba and how are they connected … with a few stations in between, Marenski in the middle (sketch)… then I went to see what is going on, as this happens the | Simple images, and place images, and geographic, colour, inner voice. Use to navigate. TEMSE. Diagram with 11 lines. |

| | | |
|---|---|---|
| | mental image comes closer and it's big and in front of my face the same as TEMSE …<br>With the third alarm the pictures in my mind was of losing all the load and all the stations. I saw the lines not carrying any Watts, just MVARs, the diagram was the same as the sketch, it was in front of my face and the geographical one behind me…<br>(Single line diagram with 11 lines) | |
| C14 | You have this picture in your mind from years of experience … and key points of reference, which tell you that whole regions are ok or not, by looking on the voltage page…without having to check the tie lines…<br>(Schematic diagrams) if I see Arnot, I see Maputo, all these areas …<br>First I see the actual area the veld, because I have been there, the picture of Witkop is clear, that comes first, … next you know if the picture gets in trouble …these lines…these transformers …with Arnot the same thing … and the Marenski line etc. …<br>I think about Marenski – Arnot, from the tie line page I see that green line coming from Arnot down to Marenski, the rest are orange lines, …<br>It's green (that line) … if that picture is out of the system that means there is something wrong with that system, because that piece of the puzzle (the line) is not there …you need to do something to make (all the time he is showing lines and movements with his hands) the picture look better without that piece of puzzle …<br>It's still an ENCOR screen!!<br>I see pictures of power stations (what they look like physically) Matimba, Duvha, Kendal, etc. …<br>I said to myself, the solution has to be within our own network …from Arnot there is a link, 400 kV, to Mozambique, It's a picture of the transformers at Arnot, the gens are not there, … now the picture is of the two gens, brown generators, on the 275 kV the transformer looks like two circles into the bus, and three transformers one on the right and two on the left … it's a combination of numbers and lines and bus-bars …<br>When things are fine, the picture is the same as when there is a problem, … when it comes up it looks like a combination … on the left there are pictures of the station (actual structure) and in front of my face there are the schematics of the network …<br>This part is green, this part is brown, when I am answering any one of the questions, is it this or that? … | Simple images, colour, place pictures. ENCOR. Inner voice. Use to navigate. Diagram with 14 lines. |

| | | |
|---|---|---|
| | it triggers this image…<br>(Single line diagram with 14 lines) | |

### D.3.2 Summary of Results

Below is a summation of the results in all the relevant categories.

Table D.3.2.A: Summary of findings from the tacit content section

| Control-ler | Imag-es | Colour | B & W | Sim-ple | Complex Other | ENCOR | TEMSE | Used to Navigate | Inner voice | Sketch lines / eleme-nts | Zoom |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | X | X | X | X | | | X | X | X | 3 to 15 | X |
| 2 | X | X | X | X | | | | X | | 22 | X |
| 3 | X | ? | | X | | | ? | X | X | ? | |
| 4 | X | X | | X | | | X | X | X | 11 | |
| 5 | X | X | | X | | | X | X | XX | 4 | |
| 6 | X | X | | X | Place | | X | X | XX | ? | |
| 7 | X | X | | X | | | X | X | | 6 | |
| 8 | X | X | | X | Geographic | | X | X | | 3 | X |
| 9 | X | X | | X | | | X | X | ?? | ? | |
| 10 | X | X | | X | Road-map | X | X | X | X | ? | X |
| 11 | X | X | X | X | Network | X | X | X | | 11 | |
| 12 | X | X | | X | | X | (x) | X | X | 3 | X |
| 13 | X | X | | X | Place and geographic | | X | X | X | 11 | |
| 14 | X | X | | X | Place | X | | X | | 14 | |

### D.3.3 Analysis

**Images:** 100% of the controllers reported the spontaneous arising of tacit imagery. The manner of their arising and spatial location within the controllers' minds is also of great significance as their location can happen to be superimposed on the physical screens leading to operating errors, particularly when a controller may be fatigued.

**Colour:** 93% (13 / 14) of the controllers reported their images either were in or included colour.

**Black & White:** 21.4% (3 / 14) reported that their images were also in black and white

**Simple:** 100% of the controllers reported that their images were less complicated than the images on the computer screens.

**Complex Other:** 43% (6 /14) reported that they also had other complex imagery arising, like maps of the country, route maps, and actual images of places. The geographical images were useful to identify where equipment is situated geographically and how it relates to other topographical factors, like proximity of substations, terrain, urban vs. rural setting, etc. However, the images of the actual sub-stations, like post cards, acted as distractions as these did not provide useful technical information.

**ENCOR:** 7 % (1 / 14) reported that their images resembled ENCOR screens only. This is quite an important finding as it shows that most of the controllers' minds have made the transition to the TEMSE image format. The controller above could be trained to make the transition as well, now that this information is made explicit.

**TEMSE & ENCOR** 21% (3 / 14) reported that they have both TEMSE and ENCOR images in their mind. The same training as above can be used to help them make the complete transition.

**TEMSE:** 57% (8 / 14) reported that their imagery resembled TEMSE displays only.

**Own Images:** 14% (2 / 14) reported that they have their own mental images, which do not look like ENCOR or TEMSE. These can be used as references for best practice protocols.

**Used to Navigate:** 100% of the controllers reported, they used the tacit mental imagery to "navigate" the contingencies in the simulator exercise.

One individual said that he only used the HMI screens to navigate, but some of his other statements implied that he in fact had mental imagery which gave him direction, he said, "There is more detail on the screen than in my mind, … in Natal it's a straight road, here its zigzag (moves his right hand). I know the basic layout and then I use the screen to go from

there." In spite of these statements he insisted that there was no mental imagery to report.

In some cases the mental manipulation of these images was a criterion of high levels of competence, as some of the expert controllers reported they could zoom in and out of their mental images, thus making it possible to see the network in perspective and thus make better decisions. Some of the others (3 / 14) even tried doing this after the exercise, and reported that it made a very big difference to how they could have dealt with the contingencies presented, and how they would have felt as a consequence during the exercise. It is interesting to note that there wasn't any notable difference between the mental imagery of novice and experienced controllers (see C7 and C13 as compared to the rest).

**Inner Voice:** 64% (9 / 14) reported that there was an inner voice (auditory) component to their tacit experience. This inner voice (s) played either a focussing enabling role, or had an inhibiting disturbing influence. For some, this phenomenon (2 / 14) was very intense with a number of voices going on at the same time. One other displayed behaviours during his working on the simulator of intense frustration, which he manifested verbally during the process as if he was expressing what was going on in his mind by saying things like, "I give up, … this is too much".

**Sketch:** 71% (10 / 14) produced sketches to illustrate their mental imagery. These images were simple and corresponded to their verbal descriptions. The shape, orientation, and features, of these sketches can be further analysed to assist MMI developers in their designs. As, if computer display designs are made similar to what happens inside controllers' minds this may reduce response times and improve other elements of their performance, such as confidence, flexibility etc. One controller suggested that the actual screen layout for each individual controller could be customised and they could select their layout when they sign in for shift work.

As mentioned in the beginning, these findings and analysis will be used in the

Conclusion section, where all the findings from the different sections of the Results chapter will be integrated.

In the next section the sequences used by the controllers to work on the simulator will be presented. These sequences consist of what the controllers paid attention to, and in what sequence, during the exercise.

## D.4 Tacit Structures

The tacit structures of the controllers' performance were extracted from the interview transcripts. The term Tacit Structures refers to the sequences, which the controllers followed in doing their work, such as looking at the computer screens, then seeing mental images, followed by internal verbalisation (thoughts), then carrying out some action, etc. These sequences were identified and compared in order to find out what are the trends, if any, and what they reveal.

**The part of the Research Question addressed here was (in bold):**

> **What are the tacit mental structures,** content and emotions, **which arise within the minds of the controllers at the NCC, as they work with the newly implemented TEMSE Windows based computer interface?**

The most important factor is whether the controllers were capable of maintaining an unfettered state of awareness, because when a person's attention becomes "stuck" then their ability to continue functioning is diminished to a great extent or is absent. It is this skill, which is paramount in this section, as one controller put it, "I feel uncomfortable …it became worse and worse, you want to give up, in my head I got that loser feeling, … even though you want to give up you can't give up, … there is no way you can ignore it, you have to fight it…" Then the inhibiting factors that prevented the controllers from maintaining a free attention were considered. Such internal verbalization(s) lead to attention break down and the associated unpleasant feelings they evoke.

Another key factor is the ability of the controllers to consciously engage with their mental visualizations, and in particular their ability to zoom in and out of the mental images they had of the network. This skill allows for flexibility of a different kind, it is the flexibility of decision-making. That is, with the ability to see the big picture and consider as many operating options as possible within the constraints of a contingency (such as area, time, equipment states etc.) *then* zoom in to operate, control strategies and opportunities for maintaining system integrity could be optimised.

The following symbols are used to create the representation of the tacit sequences:

| | |
|---|---|
| Looking externally | **(Ve),** stands for Visual external. |
| Seeing internally | **(Vi and / or Vizo, Zizi),** stand for Visual internal and / or zoom out, and zoom in, mentally |
| Hear Thoughts | **(T)** |
| Fear or calm | **(K- or K+),** stand for Kinaesthetic –ve and +ve. |
| Work on the network | (W), stands for using the mouse and the computer displays to do something on the network. |
| Attention flexible or stuck | **(ATTf or ATTs).** |

First, the relevant sections of the controllers' statements from the interview transcripts are presented below.

### D.4.1 Controllers' Tacit Structure Descriptions

Table D.4.1.A: Controllers' description of tacit structure sequences

| Controller | Information (Tacit Structures) |
|---|---|
| C1 | In the 1st incident I pulled back to view the whole and then zoomed in to work.<br>I saw the network image in my mind--- I confirmed on the monitor --<br>(he heard / thought in his mind the steps he followed to respond to |

| | |
|---|---|
| | the problem -- then zoomed in to operate.)<br>In the 2nd incident I saw (mentally) the close-up first, the transformers. Then I went to confirm on the monitor---then pulled away mentally --- then thought I need to start looking over here… etc. to see the big picture, and then zoomed in to operate.<br>With the 3rd incident I (mentally) saw the big picture first, because I knew this area would be affected… load shedding it's a scary thing… but once the decision is made it's easy.<br>To be able to zoom out and in mentally is a major skill! |
| C2 | C2: You need to see which lines can go back immediately …<br>C2: The lines do not have a big impact for me I just saw them, it was a yes or no. I just see the lines and my brain starts to see in pictures the steps that I must do… (lists the steps),…generators and caps give VARs, I see the station, I see one thing …immediately other sub stations show up on drawing,… gen and reactive equipment is one, …finally load shedding, the step you don't want to take …<br>C2: Immediately I go to the screen<br>C2: The mental image is the guide<br>I get the mental picture and I confirm with the screen…it pops out in my mind and then it tells me where to confirm<br>C2: The mental image disappears when the system goes normal |
| C3 | Int: You see a problem, and then look on the screen, and then see you have to go to the next place, because you can see the lines?<br>C3: Yes<br>Int: So there's no mental strategy that you follow…?<br>C3: No… in a way I suppose … nahhh …<br>Int: The overall action plan, how do you process that in your mind …?<br>C3: I can't tell you … it comes automatically<br>Int: What comes automatically? Words, pictures, how do you process it?<br>C3: …no I can't tell you …I know where to click to find what… I know where the breakers are … you click on a station and see which feeders come out because you can't remember all of them …<br>Int: So, the strategy you use is to look on the screen, and see what follows and move like that, …<br>C3: Yes<br>I know the basic layout and then I use the screen to go from there<br>Int: Is there a procedure you have?<br>C3: Yes there is a kind of a procedure … explains in voltage level steps (275, 400 kV etc . … looks away, its Camden etc.,) then I follow the screen. |
| C4 | Int: What was going on in your mind?<br>C4: I saw the alarm, then I went to see the overview… then I went back to Matimba…etc.<br>From the top right hand side it went to the top left hand side where |

| | |
|---|---|
| | Matraco is, … I work until its sorted out.<br>I was seeing this mental picture …I know its low voltages … I thought this is bad … I looked on the screen then the voltage page was here (top right), and then I confirmed this on the screen. Then the mental picture was gone when I confirmed. Then another mental page popped up on top right and I went to confirm again… |
| C5 | When the transformers tripped … I was thinking that I need to shed, shed, shed, load…but then I got to move somewhere else because I would shut down the whole sub station.<br>… shedding a lot of load would shut the sub station down so …I thought I have to go elsewhere… I also think of other places, what I saw in my mind, I saw Arnot feeding Marenski … shed load at Marenski… I was looking at the voltages and the system …<br>C5: We lost the two transformers, then all the voltages went, … then I took long to think … I was looking at those voltages on the screens …<br>Int: Did that help you<br>C5: No …<br>Int: What helped you in your mind?<br>C5: The little voice, … that is why I went to Marathon … I wanted to say to Jan (simulator trainer), stop I can't do it … I lost concentration I thought, this is too much, … then another voice said, you can try this … shed load … I wasn't sure if I should listen to it. |
| C6 | C6: If you are on the voltage desk you have an alarm page and a voltage profile page, then you look for what is the cause of the trip etc., … is it weather, fires, etc. We close the line after three minutes, if it trips again we dispatch someone…<br>We try and find equipment that can help raise the voltage, finally we load shed<br>Int: How do you analyze it<br>C6: I look at the screen at the colours its attracting your attention.. you look at lowest voltages "let me go to that station and shed the load" …no mental image just from the screen …all confusion is gone back to normal you identify what you see what the problem is … I must go and look on the screen and move on … once I went to that screen …where do I start? I can ask to have load shed and they know which load to shed…<br>By looking at the screen you restore the network until the mental picture clears up … up to the point where I see the same as the screen no more or less |
| C7 | Int: What do you see in your mind while you do all that, is it images or is it a voice / thoughts that you hear?<br>C7: It's that blue picture which highlights when the voltages go low … no schematics just a voltage number (against a blue background)… I went to the screen to look … when the second thing occurred I went to Arnot…I had an orange background with Arnot on |

| | |
|---|---|
| | it, surprising it wasn't blue… then I thought of Mozal, … I could see that schematic diagram (sketch on paper) in the mind, this is what I saw, … and describes the voltage relationships from HV to LV down to Mozal.<br>I asked for load to be shed, … I saw the effect on the voltages but it was still bad at Komatipoort … then I asked to open another feeder at Komatipoort …but could not, then I started looking for options …<br>I started scanning in my mind, I have a schematic diagram what feeders can be coming out, its blue for 132 kV, I see Marathon (substation) blue as well…it triggers me to have a look on the screen.<br>C7: In my mind I see an overview, its blue, it just triggers me to look further, it's a simplified drawing to help me know where to go and look… |
| C8 | when Jan (simulator trainer) told me about the voltages I went to that picture behind there, to fix, to boost the voltage.<br>I look at the colours and the numbers on the screen, … she focuses on the screens<br>C8: Its what I saw the different colours …the blue colour on the voltage side … the colour was the first thing that jumped out …. it's busy flashing … I thought reduce load …<br>when the transformers tripped I had to go to the alarms to check what tripped I couldn't see the power flow that would change the power flow when the alarm came I had to go in my mind to check what is wrong, I have to go see what is going on … with the alarm I look on the screens, then this picture became bigger (sketch) … I see what's going on when all is fine with the alarm all the big stuff disappears and smaller things become clear… the regions … interconnected, … then when new alarms come you look at the screen again and new pictures become big. |
| C9 | C9: If you look at the volt page (lists of numbers)<br>C9: …information comes off the screens … not sure what goes on inside…its like a sixth sense … I need to inform the shift manager … I look at the power stations … I look at the screen and the effected area … then I think what's happening in the "black hole " area … then the voltages collapse then I think "oh no" the feeling is strong… oh what next … I was trying to recall all the regulations but not getting them up (mentally) in time with the events… I have to get rid of load … I lost it!!<br>---<br>Int: At a time when you knew what to do what happened? **If there were no consequences what would you do?**<br>C9: By means of recall you do what you need to … it happened that way there, it should happen this way here…what comes up brings up procedures and sequences … it's a diagram green for 400 kV, orange for 275 kV etc. …<br>C9: He easily gives a good set of steps with confidence… providing |

| | |
|---|---|
| | reasons and going from step to step with alternatives.<br>Looking at this I would have opened the … line because of the Megavar load at … and there I could have knocked off some load.<br>C9: He goes back to the screens and starts talking, and going through all the steps taking into account other loads further away, and moving from one stage, to the next, evaluating the options and making decisions without pausing… |
| C10 | The system did not appear normal … I saw the voltage value numbers and saw that they were not normal compared with the normal values for that area.<br>Int: Were there pictures in your mind?<br>C10: I look at the substation it should be (gives the values for the voltages) It shouldn't be like that,… made me uncomfortable …<br>C10: I see that we are sitting with … (kV), this its close to collapse point, it feels its close … right next to you … you want to keep as far as possible from it.<br>C10: I see the whole lowveld network … and how it will benefit<br>C10 The mental picture is like a road map … I say "if I don't do something there" …<br>C10: The network and I "we have a feeling for each other now" I just want to keep away from the "collapse point" … the voltage screen gives me direction … for detail I go to the station screens … voltage numbers first … station schematic next<br>I see the whole Arnot picture … the picture in my mind is what you expect to see, then you look at the screens and compare… not every fine detail.<br>When the Arnot transformer tripped you tend to have a focus point … I will see this in my head, this is much prominent, if you close a breaker you expect it to go from green to red, if it does not it feels different, … funny…<br>in this case I was just waiting for the worst, the network going down hill, to the "black hole" … I feel uncomfortable …it became worse and worse, you want to give up, in my head I got that loser feeling, … even though you want to give up you can't give up, … there is no way you can ignore it, you have to fight it… |
| C11 | I went through the regions, Central, Natal, Koeberg, Western Cape, Western Cape, …etc. … I was tangled … because I was looking at the numbers on the voltage screen the tie-line screen was the second priority, … the mental image was less of a priority … I knew I had to shed the load but I didn't, I kept going round and round because the line was closed and it should not be.<br>C11: (Lists the sequence that he followed) Matla, Duvha, Arnot, …etc is a list of words in my mind… in this case I saw the screen, then I thought "load shed"…then I saw the (name of a line) line at zero …then I went to that line on the screen, and referenced the screen image to my mind image, which did not make sense, so I got |

| | |
|---|---|
| | stuck… |
| C12 | C12: I saw the transformers, then the two lines tripping from Matimba, … normally I look at the voltages then I would go and look at Matrako, the voltages were fine, then saw a problem in this region …<br>C12: I have to prevent the voltage from collapse… the two lines tripped the voltage started going down …<br>C12: I've checked the alarms I saw Witkop-Matimba trip, then voltage problems, … these numbers mean voltage collapse …black out in that region<br>At Foskor, fortunately, there was one which I could close …then I think of Cedine sub-station, the first thing that strikes me is the 400 kV bus-bars as green stripes and I see the two caps, … but unfortunately they were not available … I see them as part of the network but I am not concerned with the linkage points …<br>Then I go to Maputo and close the cap there … the voltage did not go up enough… I look at the list of voltage numbers … I look for different numbers, it depends on how low the voltage is, … I have a comparison in my mind I run my voltages at 292 kV at Maputo, and I see that number in yellow, very small number, in front of me, close, that number looks like ENCOR, … it bothers me that the numbers on the screen do not look the same as the ones in my mind, … but that is the system so I work with it.<br>C12: (He lists the steps that he followed in sequence) … In my mind I had a picture of the Matrako network with voltages declining, … I went to the voltage page to verify, I was expecting the voltage to decline further, which was true, then I tried to shed some load. I tried to open a Mozal pot (smelter), … |
| C13 | Int: When the first contingency happened your first concern was frequency?<br>C13: Yes then I went to Matimba and asked to drop load, I then checked the voltages in the stations, … then the second contingency came and I felt frightened, the picture in my mind was first of the whole country then I went to Arnot and Matimba in my mind and then looked at the screen, then back in my mind, and zoomed in further, to the double bus-bars, and then I saw the loads being tripped. Then I saw the voltages were still going down and thought where can I get the VARs? I knew in my mind maybe I can get them from Matimba. Then I wondered if it will affect the voltage, and I must ask for advice first, but I was alone and the transformers are blinking and if I shed some load things may improve. Load shedding was the main strategy<br>then I thought of restoring … the voltage was zero and I couldn't do anything, the last alarm was the worst one, then I went back and started at that point … |

| | |
|---|---|
| C14 | C14: The voltage profile was not good when I took over, so I first had to sort that out, then when line 1 and 2 tripped, in the back of my mind, I knew there were problems in that area, from before…<br>C14: I had this picture …<br>C14: What you see on the screen, the voltage profile, is not good, you need to do something, then you get a picture this is a bad profile.<br>C14: If this and that happens, you get into more trouble, … once you look at this area and see all these funny voltages there are certain contingencies that start playing in your head, and critical faults that can put you in more trouble, what if Matimba trips? etc…<br>C14: You start doing things that need to be done…you check if all the caps are in … you ask if all the caps are in, then go to the screen and check … where they are open you close them…<br>Then the two lines tripped that was an interruption of my loop of working…that interrupted my routine before finishing … and this was critical…and I asked myself, have I survived?<br>I have to move quickly…to counteract the action of the automatic tap-changers, to try and arrest the situation… I can push up the voltages by 10% from the power stations… immediately without looking at the alarms, you can get into picture mode and then you go on… |

### D.4.2 Summary of Tacit Sequences

Table D.4.2.A: Summary of tacit sequences extracted from the controllers' descriptions

| **Controller** | **Sequences of Tacit Structures** | **Attention state** |
|---|---|---|
| C1 | Ve Vizo Ve Vizi T Ve W K- Vi K+ | ATTf |
| C2 | Ve Vizo Vizi K- Ve W K+ | ATTf |
| C3 | Ve ((Vi) or (T)) W Ve W | ATTf? |
| C4 | Ve Ve Vi T Ve Vi W Ve Vi stop K+ | ATTf |
| C5 | Ve T K- Vi T- Ve ATTs T- ATTs T+ | ATTs |
| C6 | Ve Ve T W Vi Ve W Vi Ve K+ | ATTf |
| C7 | Ve Vi Ve Vi W Ve Vizo Ve Ve W K+ | ATTf |
| C8 | Ve T Ve Vi Ve W Ve Vi K+ | ATTf |
| C9 | Ve K- Ve T K- T T K-<br>(alternative state without consequences, see table above under (C9))<br>Ve Ve Vi Ve W K+ | ATTs<br>Note:<br>ATTf |
| C10 | Ve Vi K- Vi K- Ve W Ve Vi K- | ATTf |
| C11 | Vi Ve K- Ve T Ve Vi K- | ATTs |
| C12 | Ve Ve T Vi T Ve W Vi Ve W Ve Vi K- Ve | ATTf |

| | | |
|---|---|---|
| | W | |
| C13 | Ve Ve T W Ve Ve K- Vizo Vizi Ve T Ve T Ve K- Ve | ATTf |
| C14 | Ve W Vi T Ve Vi K- W Ve W Ve T K- W | ATTf |

**D.4.3 Analysis**

Looking at the results tabulated above, the common sequence aspects of what most controllers did was:

Ve – Vi – Ve – W – Vi - … Where:

Ve (Look outside on the monitors),

Vi (Look inside to make sense of the situation and identify alternatives),

Ve (Verify on the monitors),

W (Work on the network),

Vi (Look inside to see if the new situation is acceptable), etc.

Continue on …

This loop was repeated with variations until the situation was addressed one way or another. Together with the above were interspersed the extra dimensions of inner zooming, and thoughts (internal dialogue), which either assist or inhibit performance. Another common factor was the arising of intense feelings (pleasant K+, and unpleasant K-), which are dealt in a section of their own, under the heading Emotions. Unpleasant feelings (K-) were mostly motivators for action. However when these have to do with negative consequences to the network, and by extension for the controller, they can be paralysing. Management policies within the NCC need to be considered here, with respect to the punitive measures in place for actions, which lead to network failures. In this respect the studies on stress, conducted by the royal Navy in the UK (Bridger 2007), seem to confirm this as it was shown that it's relationships with people that cause stress, while adverse working conditions mostly cause fatigue.

**Attention** 78.6% (11 / 14) of the controllers demonstrated that their attention was free to continue working looking for ways to contain the contingencies. 21.4% (3 / 14) appeared to be unable to continue in the face of what seemed to be an impossible situation and their attention was "frozen" or stuck.

To shed some light on this phenomenon here is one interesting example. One of the controllers initially got stuck and could not continue with the work, as contingencies kept on getting worse. The same person however, after the formal interview was over, was able to change his state of mind to such an extent that he was able to find alternatives and sort out the situation without any difficulty at all. Now what was it that made this possible? It was the fact that it was put to him, "What would you do if there was no threat of reprimand if things got out of hand?" Suddenly his mind came to life and he was able to provide solutions to all the contingencies of the exercise. The sequence of his reports about his work before and after is captured in the tables above under section (C9). Looking at the two sequences the main difference is the great deal of internal verbal processing (the tonality in particular) going on in his mind.

**Zoom in and out mentally** 28.6% (4 / 14) of the controllers spontaneously reported that they would zoom out in their mind to see a broader picture of the network, in order to decide how best to proceed. One in particular consciously did so as a result of feedback given to him at an earlier time. On the other extreme 21.4% got stuck on a particular image and could not proceed at all when the contingencies got to a certain point. **The zoom out (Vizo) step seems to be a key component of high expertise levels** as it provides the controller with the opportunity to consider large sections of the network before making decisions. On the other hand *uncontrolled* zooming in (visual mental fixation, (Vizi)) seemed to be a sign of reduced expertise levels, as alternatives are not seen and it becomes difficult to control the

network successfully, this is concluded from the descriptions the controllers gave.

Further, two of the controllers were asked after the interview, “What would happen if you would zoom out see the whole network first then decide what needs doing?” In both cases they reported that their skill level would be much higher and that they would have had alternatives from the start. In order for a controller to do this, they need to have a good mental image of the network, as well as to develop the ability to remain calm under contingency conditions so that they can mentally zoom out in order to decide what to do. This mental dexterity seems to be part of the “best practice” strategies used by the most competent controllers. Together with emotional calm under pressure they seem to be the topmost mental management skills a top controller has to develop.

### D.4.4 Inhibiting Factors

**Inner Verbalization** 21.4% (3 / 14) controllers demonstrated that inner verbalizations affected them negatively. This suggests that as long as they had thoughts / words filling up their mental landscape there was no place for anything else. Together with these thoughts were strong emotions of fear and frustration, which seemed to inhibit them cognitively and physically. This phenomenon (lots of inner dialogue) was observed with one controller and was less dramatic in the other two. This implies that verbal thought processes which flood a controller’s awareness both inhibit his work and, it is suspected, create long term stress / strain problems. This last possibility could be monitored and its long-term implications assessed as a matter of urgency, as stress problems are quite common in the control room.

**Other Factors** Many of the controllers reported that load shedding is a great emotional barrier both in the Eskom control room as well as in other control rooms around the world (one person reported that this was one of the highlights

> in a recent international gathering of controllers). Desensitization training in the simulator should become a standard measure to counteract this difficulty. There also seem to be a lot of emotions around the stigma attached to load shedding, and the possible consequences for the controllers, which cause paralysing feelings of anxiety. Management must address this aspect, as a matter of urgency, as this is a "Russian Roulette" phenomenon with dire consequences for all concerned.

In the next section will be presented the changes in working style and other adaptations, which the controllers had to make in order to work on the new TEMSE interfaces.

## D.5 **Adjustments:** From ENCOR to TEMSE

In this section the information pertaining to the transition from ENCOR to TEMSE is summarised. The controllers' comments on how long it took them to adapt from ENCOR to TEMSE, the type of adjustments they found the most difficult, and any other comments about the two systems are tabulated at the end of the section.

**The part of the Research Question addressed here was (in bold):**

> **What are the tacit mental structures, content** and emotions, **which arise within the minds of the controllers at the NCC, as they work with the newly implemented TEMSE Windows based computer interface**, **compared to the old ENCOR interface?**

The relevant sections of the controllers' statements from the interview transcripts are presented below, as well as the years of experience on ENCOR and TEMSE, how long it took for each controller to make the transition, the type of images they have in their mind now, and the type of adjustments / difficulties with TEMSE they had to make.

### D.5.1 Summary of Results

Table D.5.1.A: Summary of controller comments about adaptation times

| Contr -oller | Years of experience ENCOR / TEMSE | Transition time ENCOR to TEMSE & Image now | Adjustments | Controller Comments |
|---|---|---|---|---|
| C1 | 12 / 2.5 | 6 months TEMSE | Hand on mouse | The biggest change for me moving over to TEMSE was that I do not use my right hand (left handed), as TEMSE is Windows based and mouse driven. It was like the hand wanted to do things by itself… it was a major adjustment as with the mental imagery it took about 6 months to adjust. ENCOR had colours for breakers, green for open, and red for closed I could process all that info by just scanning and seeing the green ones to identify the affected areas. With TEMSE alarms come up in a list which keeps moving down as more alarms come on. I want to see all the breakers at once during a major incident. ENCOR is best for that. |
| C2 | 9 / 1.5 | Own mental images, does not use TEMSE | Off shift | Int: How long has it taken you to decompress after moving out of the control room? About six months |
| C3 | 20? / 2.5 | 3 weeks TEMSE | None | No, not really, its about the same ... we switched over very quickly it didn't take long to get used to it … two, three, weeks … eventually when they switched over I didn't have problems Now it looks like TEMSE |
| C4 | 4 / 2.5 | 2-3 months TEMSE | None | It's like TEMSE ENCOR is gone now …the pictures look like TEMSE. Compared to ENCOR this system is better, … you can do so much more functions … I'm used to it, you just click and you get the loadings, it's quick, just a click and you can see the limits on lines …this works for me… TEMSE can freeze up, ENCOR was |

| | | | | |
|---|---|---|---|---|
| | | | | more reliable…This system (TEMSE) can go off for 5 min max… It took about 2-3 months to adjust to TEMSE. |
| C5 | 8 / 2.5 | 2-3 months TEMSE | Mental adjustment | It took a while maybe 2 or 3 months to adjust, I thought I will have to change my mind, and change to TEMSE; otherwise I would make operating errors. |
| C6 | 1 / 2.5 | 3 months TEMSE | None | TEMSE because you get it all on the one page encore you have to look on the key board can't find the key for something you get lost on the key board you look but cant see it… this is much better more direct access click, click, you get what you want… Yes, it shows everything on one page, it's much better than ENCOR…you don't have to go behind to another page …3 months to adjust. |
| C7 | 0 / 1.5 | TEMSE | None | When I started working with TEMSE my mind adapted quickly to it… ENCORE was a bit similar to a system I worked on before (SMART system) I came here and that it was confusing as they were similar, but not the same…TEMSE is very different so I could distinguish it from what I was used to ... |
| C8 | 9 / 1 | Own mental images | None | Neither … they do not show this (holistic view). I would choose TEMSE because you have better options. You can have a geographical map with TEMSE but it is static. If you had the load flow and the voltages this would match the picture in my mind that would be perfect. |
| C9 | 25 / 2.5 | 8-12 months TEMSE | Mouse, alarms | ENCOR is so far in the past, it's a shut book (points to behind his head) …I struggled in the beginning when we changed… the mouse operation, the alarms, all changed. The thing I have against this is the amount of alarms we get plus some new ones that I do not understand…ENCOR did not have the same volume of alarms … on a morning pick up you cannot keep up, |

| | | | | |
|---|---|---|---|---|
| | | | | you clear alarms now, but the page will be full again… About 8 months to a year to adjust…<br>I see TEMSE images in my mind. ENCORE images have faded …I would be slow if we went back on to ENCOR. |
| C10 | 16 / 2.5 | 2-3 months TEMSE & ENCOR | Slow response from TEMSE | ENCOR was faster more accurate … now I'm getting used to this. Its not the picture per se, it's the operation … you close the breaker it shows you, breaker closed…this thing takes long it is frustrating, also the accuracy of the numbers is not too good. Now the pictures in my mind clash with the screen … the colours … some time ago we closed the line, no indication. On the tie line we saw the load flow so we assumed the line closed but the breaker closed after 15 min! TEMSE is working, we just complain … it could have been better … we need true values and faster response times … the colours etc., that does not bother me… you cant wait for information. … It took me two to three months to get used to TEMSE… |
| C11 | 7 / 1 | 3 months TEMSE & ENCOR Off shift | None Picture method of learning the network | I have done no work with TEMSE just with ENCOR. It took a year (2007) to get used to the TEMSE display, because I was out of the control room, … still ENCOR would be easier as I spent 7 years with it…<br>If I had to do it straight away, it would take about three months to adapt the pictures in my mind to TEMSE, … I do not know if any one else used this picture technique of memorising the network, another shift manager too, recommended this way of learning, the lines, the transformer sizes. In my mind I look at the whole system … |
| C12 | 9 / 2.5 | 2 Years ENCOR & TEMSE | Alarms | It was difficult in the beginning, ENCOR it is now disappearing, even now with the alarms I took time to find out where the alarms were, they appear |

| | | | | |
|---|---|---|---|---|
| | | | | in a different way (on TEMSE). About 2 years to adapt to TEMSE. |
| C13 | 0 / 0.5 | TEMSE | None | Yes some time I do (discuss the HMI images) with the shift manager. He (the shift manager) uses images and the screens and drawings to explain … he is uncomfortable with TEMSE. Time is the problem, it's slow, the images are more or less the same but slowness is the main concern. |
| C14 | 10 / 2.5 | ENCOR Focuses on voltage numbers | Voltage value colours | In the ENCOR there was red for low or high voltage, TEMSE has blue for low voltage that creates conflict inside me … TEMSE has red for high voltage… it's a bit confusing, … sometimes your (past) experience can let you down… Not really, there was a demand for TEMSE to be as close to ENCOR as possible, except for the colours… I am not sure if this was the right thing to do… it might have been better if it was very different so as to make us reprogram your "software" (mind) completely, like an upgrade. Instead we still have the old pictures in our minds, whereas the network has expanded with new equipment and that creates problems… |

### D.5.2 Analysis of Results

**Duration Of Transition**

42.8% (6 / 14) controllers reported that it took between 1 – 3 months to adjust to the TEMSE system.

14.2% (2 / 14) controllers reported they took 6 -12 months to adjust.

7.1% (1/14) controller reported it took about 2 years to adjust to TEMSE.

14.2% (2 / 14) controllers reported that they did not have ENCOR experience so there was no transition time as they were new to the control room environment.

14.2% (2 / 14) controllers reported that they have their own mental images therefore the transition did not influence these.
7.1% (1 / 14) one controller reported that he is still going through the process of adaptation two years after the changeover.

**Type of Mental Images** (They are the same as in the section on Tacit Content)

**Difficulties with The Transition**
42.8% (6 / 14) reported having difficulties in making the transition, with the following:

- Mouse use
- Mental adjustments
- Alarm depiction
- Slowness of response of the TEMSE system
- Voltage value colours

50% (7 / 14) did not have any difficulty with the transition, or did not have to make any major adjustments, or did not have much ENCOR experience.

One of the controllers used in the study did not work with TEMSE in the control room at all, as he was off shift before the transition. However he has used the TEMSE system in his new job for over a year to perform network studies etc.

**Other Comments About The Two Systems**
The following comments were made with respect to the differences between the two systems. They are grouped in two categories positive and negative.

**Negative comments about TEMSE:**

- ENCOR had the following **colours for breakers**, green for open, and red for closed. I could process all that info by just scanning and seeing the green ones to

identify the affected areas. I want to **see all the breakers at once** during a major incident. ENCOR is best for that (controllers C1, C14).

- With TEMSE **alarms** come up in a **list** which keeps moving down as more alarms come on (controller C1).

- I want see all the breakers at once during a major incident, ENCOR was green on black background… TEMSE does not do that (controller C1).

- The thing I have against TEMSE is the **amount of alarms** we get plus some new ones that I do not understand…ENCOR did not have the same volume of alarms … on a morning pick up **you cannot keep up,** you clear **alarms** now, but the page will be full again… (controllers C9, C12).

- Sometimes the coms have failed, you close a breaker and it still shows that the lines are live, … **it can freeze up,** ENCOR was more reliable…This system (TEMSE) can go off **for 5 min** max… (controller C4).

- **ENCOR was faster more accurate** TEMSE is slow… (controller C13).

- ENCOR! Its not the picture per se, it's the operation … you close the breaker it shows you, breaker closed…this thing **takes long** it is frustrating, it took 15 minutes for the breaker to close… you cant wait for information (controller C10).

**Positive comments about TEMSE:**

- **You can do so much more functions** … **you just click** and you get the **loadings**, it's quick, just a click and you can **see the limits on lines** (controller C4).

- TEMSE because you **get it all on the one page**, ENCOR you have to look on the key board can't find the key for something you get lost on the key board you look

but cant see it… this is much better more direct access click, **click, you get what you want**… (controller C6)

- Yes, it shows **everything on one page**, it's much better than ENCOR…you don't have to go behind to another page … (controller C8)

- I would choose TEMSE because you have **better options (**controller C8)

- TEMSE is working, we just complain … it could have been better (controller C10)

In the next section we will identify what other external factors influence the controllers' working lives by assisting or inhibiting their performance.

## D.6 Other Important Factors

In this section a number of factors, which were identified as significant to the controllers' performance were elicited, in order to find out which enhance and which inhibit the controllers' performance.
The controllers' responses to the question about what other factors enhance or inhibit their performance are extracted and presented in Appendix E.

The factors were:
People
Knowledge/Experience/Skill
Equipment
Environment
Prospects
Conditions
Requirements
Management

Family

Communication

Other

The findings are summarised in two columns one for those factors, which enhance and one for the factors, which inhibit performance.

It is important to note that since not all the personnel in the control room were interviewed the findings represent the views of those who did participate (14 / 28), about half of the total staff complement.

These findings therefore should be treated as an initial comment on the situation. On the other hand, the items, like people etc., which received very high response rates can be taken to represent majority views, and as such receive the required attention.

### D.6.1 Other Factors Sequence List

Table D.6.1.A: Performance Enhancing and Inhibiting factors

| Controller | Work Enhancing Factors | Detrimental Factors |
|---|---|---|
| C1 | Knowledge – people - communication. | Equipment - communication |
| C2 | Knowledge and experience – people support- communicate openly - the computer system - management support. | Graveyard shift, (14:00) - monotonous activities – “us and them”- negative person - relaxation of processes - questioning of authority - management support - meet others in the field - from shift to pension |
| C3 | Equipment -people - interest is paramount - screens | Family is a big factor - windows - chairs -career opportunities |
| C4 | People | I need new challenges… |
| C5 | People -knowledge - the manager - equipment - room is cold - prospects - requirements | Family was the cause of worries while at work |
| C6 | Team – windows - prospects - qualifications | Grading is not right, |
| C7 | First family - then people – | At night the light - too many |

| | | |
|---|---|---|
| | environment - equipment. | regulations -laws come from above - management |
| C8 | First family – knowledge - equipment – people - environment. | Windows - the promotion process is not applied equally - some Power System Managers do not help others to grow |
| C9 | Knowledge and equipment come first - people - family - shift work - training on the simulator - relaxed shift | Light above my head - prospects -having to do others work |
| C10 | Equipment - health - shift work - - the "living beast" is never the same - when I leave here I leave it behind me. | |
| C11 | Career prospects most important - environment (he means the people in the environment) - manager – chairs – to have a goal in life. | Manager – people – unfair management decisions |
| C12 | People – equipment –environment – family - shift work is more flexible. | Opportunities not clear and transparent - support, (technical & further studies) - customized screens - do I have anywhere to go? |
| C13 | First the guys - my ability - equipment - shift work - my family. | Shift work at first |
| C14 | People – relations – knowledge - night shift and weekends we have freedom. | What makes work most difficult is also people - equipment TEMSE slow - low lights a jail - day shift management coming in and out – inconsistencies. |

### D.6.2 Important Factors Summary (Performance Enhancing)

Table D.6.2.A: Summary of responses from the Performance Enhancing factors column. (The numbers in the columns represent the order of priority given by each controller.)

| Contr-oller | People | Knowledge Experien-ce Ability | Equipment | Environment | Family Supp-ort | Prospects | Management | Communication | Requirements | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 2 | 1 | | | | | | 3 | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| C2 | 2 | 1 | 4 | | | | 5 | 3 | | |
| C3 | 2 | 3 | 1 | | | | | | | |
| C4 | 1 | | | | | | | | | |
| C5 | 1 | 2 | 4 | 5 | | 6 | 3 | | 7 | |
| C6 | 1 | 4 | | 2 | | 3 | | | | |
| C7 | 2 | | 4 | 3 | 1 | | | | | |
| C8 | 4 | 2 | 3 | 5 | 1 | | | | | |
| C9 | 3 | 1 | 2 | 5 | 4 | | | | | |
| C10 | | 2 | 1 | 3 | | | | | | |
| C11 | 2 | | | 3 | | 1 | 2 | | | |
| C12 | 1 | | 2 | 3 | 4 | | | | | |
| C13 | 1 | 2 | 3 | 4 | 5 | | | | | |
| C14 | 1 | 2 | | 3 | | | | | | |
| **Total** | **13** | **10** | **9** | **10** | **6** | **3** | **3** | **2** | **1** | **1** |

Looking at the results of the table above it appears that the overall order of what it is that makes working in the control room better is as follows:
People – Knowledge/Experience/Ability –Equipment – Environment – Family – Prospects – Management – Communication - etc.

These are not definitive for everybody as for some People come first while for others Knowledge etc. However the top four fall within the scope of what can be done within the control room to improve working conditions.

### D.6.3 Important Factors Summary (Performance Inhibiting)

Table D.6.3.A: Summary of responses from the Performance Inhibiting factors column. The numbers in the columns represent the order of priority given by each controller.

| Controller | Management | Environment | People | Prospects | Equipment | Communication | Family | Other |
|---|---|---|---|---|---|---|---|---|
| C1 | | | | | 1 | 2 | | |
| C2 | 4 | 1 | 2 | 3 | | | | Pension Processes |
| C3 | | 2 | | | | | 1 | Career |
| C4 | | | | | | | | New challenges |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C5 | 1 | | | | | | | |
| C6 | | | | | | | | Grading |
| C7 | 2 | 1 | | | | | | |
| C8 | 2 | 1 | | | | | | |
| C9 | 3 | 1 | | 2 | | | | |
| C10 | | | | | | | | |
| C11 | 1 | | 2 | | | | | |
| C12 | 2 | 3 | | 1 | | | | |
| C13 | | | | | | | | Shift work |
| C14 | 4 | 3 | 1 | | 2 | | | |
| Total | 8 | 7 | 3 | 3 | 2 | 1 | 1 | |

The following factors were identified as not being conducive to optimum performance in the control room, in order of importance:

Management issues – Environment – People – Prospects – Equipment – etc.

From all the above it would be reasonable to surmise that for performance to improve in the control room the inhibiting factors should be removed and the contributing factors should be enhanced.

This means that measures could be taken to address the management practices and processes, remove the environmental inhibiting factors (such as harsh lighting etc.) and create a career path, which allows progression beyond the confines of the control room itself for the controllers. Together with these all the other minor factors should receive due attention as they may affect individuals and so they should be treated as such (such as transition to pension etc.).

Then on the positive side human relations should be made a top priority. This can be achieved by complete shifts working together in the simulator room in order to observe technical as well as interpersonal dynamics, and then apply remedies before contingencies take place.

Simulator training would address the knowledge and working expertise requirements, as well as make it possible for teams to become streamlined and work as one under adverse conditions.

The rest of the factors could be addressed on an individual basis, as per individual needs.

Finally, all the above should be regarded as processes not as once off interventions. The final aim could be to create an open ended environment in which controllers can thrive by being introduced to the environment in a practical hands on way, progress through it to higher positions as per individual aspirations and with the full support of all concerned. There should also be enough redundancy built into the controller numbers so that if a few are transferred to other sections there isn't a vacuum left behind.

The next section is about the controllers' opinions about the interview process itself. That is, we will find out what they thought about discovering all the things that they did about themselves, and the complexity of the work that they do.

## D.7 Value

In this section we asked the controllers to say what they thought about going through this whole process. The question put to them was: "Was this process worth your while?" No further prompting was made at the beginning of this section. Some answered simply, while others had a lot to say in which case further questions were asked.
First, here are the controllers' responses.
These are followed by a summary and an analysis.

**C1.**

C1: There is a lot of value in this, … the awareness you get out of it … as a learning tool.
Int: Is State Management a good thing to facilitate performance?
C1: Yes.
I made a list of all the factors that lead up to an incident. Is it lack of training; is it lack of sleep, … etc?
The single common problem from all these areas is communication. Communication between two guys working on the same thing, or from control room to control room, or with some one out on the field. In nine out of ten incidents, it's communication.

**C2.**

Yes …

**C3.**

Yes … to see yourself work.

**C4.**

Yes. This exercise broadened my mind; it revealed what goes on mentally. There are ten things going on inside, for every one thing you do, and I liked to see that I was so comfortable working by watching the video of me working on the simulator, and to see how well I did.

**C5.**

5: Yes, especially the part about zooming out, it teaches you that you don't have to rush; you need to do your assessment and its ok if it's costing more.

Me: How do you feel now?

5: It woke me up, I feel good (smile).

**C6.**

Yes

**C7.**

Yes

**C8.**

It is a useful exercise; otherwise you withdraw from your inner self. It's good to know what you can do to change, it is very useful. Each person should have a sense of ownership for your desk, in spite of the shift manager. To be trained how to make decisions as a team is important. Then there is no need for a second shift manager when things go wrong. We should be trained to work as a team. If you say I can only do certain things, I switch off …When there's an incident then you (the shift manager) are doing things by yourself, you don't train me you don't trust me to ensure that everything is done right. If you are not trained you can't work properly.

**C9.**

Yes … the fear factor!! To see me working was something.

Thank you.

**C10.**

I look very calm on the video, I thought I was more jittery, I had a different impression it was nice to see me so calm…I thought was it really me? (laughs)

**C11.**

This type of exercise can help the younger guys, the older guys are set in their ways, they are in their comfort zone … One of the biggest reasons I left the control room was that you are not allowed to think inside there. Most people feel inferior, you can't think for yourself…

**C12.**

Yes it is useful, it's nice to see how you are under different situations, it makes you aware of things that you were not aware of .

**C13.**

Seeing myself on video was a good thing, I wanted to see my face; I always ask myself how I behave?

Yes, it was worth while, these questions helped me find out more about myself and how I am thinking …the pictures as they arise … if we can do it again in six months … can you give me feedback about me?

My weakness is communication, when I get to know the people its easy … I wanted to do too many things before, now I have my priorities and things happen. Gavin (system engineer) and Manie (power system manager) help me and I am working on that and communication skills, they have improved, I am confident when I know something …

**C14.**

I think it's worth it … because it gives you an opportunity to stop and analyse everything, especially inside … if we are left on our own then what? …

There are many things we do and we are at pains to explain it to someone who knows nothing, it's complicated (what we do) we take it for granted; … we don't realize what goes into it.

This kind of process helps us to realise what we really do… that awareness is there now, … there is more to what you are doing …there is more to it…

This process it also helps and assists as part of conflict resolution, … not long ago we were arguing (a person off shift and I) about something that happened, that I never did that (during an incident)… later I checked the voice recorder and I realised from the first

word that I had nor heard what he was saying, because my mind went to a previous issue…if I had given him a moment to listen to him, to ask a few questions and get what he wanted, … we were not talking about the same thing… we were talking about a different time window,… and now I realised I was not arguing about the same thing. …

### D.7.1 Analysis

All the 14 controllers answered yes to the question.

It should be noted again that for just about everyone interviewed, the tacit domain is unfamiliar ground. Therefore to bring awareness of the hidden aspects of performance to the controllers' minds was a gratifying experience as when the tacit domain became apparent they all seemed to have a profound experience almost like a lucid dream state (LaBerge 1990). This is consistent with findings, which suggest that when higher brain functions switch on (visual cortex etc.) the brain "lights up" under fMRI scans to reveal a lucid dreaming type experience (LaBerge 1990). More specifically:

The words: **awareness, see yourself, aware of** (hidden) **things, and see myself,** imply self-awareness which is a prefrontal lobe ability activated during a lucid dream (LaBerge 1990).

Below are some samples of indications of brain region activation as per the controllers' statements.

The words: **zooming out, and pictures as they arise,** imply occipital lobe (secondary, associative, visual cortex) activity.

The words: **fear factor,** imply limbic system activity associated with strong emotions.

The words: **broadened my mind,** imply new relationships (associations) and awareness, which is an indication of parietal lobe activity.

The words: **analyse everything, … hear a voice inside,** imply temporal (language) and frontal lobe / parietal lobe (for analysis), activity.

From all the above, the term **awareness** is the most important, as awareness (prefrontal lobe activity), is the key factor in self-development (performance improvement) (LaBerge 1990) as well as resilience (the most important anti stress factor) (Bridger 2007).

Through this type of activity the existence of the possibility of self-awareness of the tacit imagery, sound, and sensations, has made it clear to the participants that it is possible to be aware and to directly interact with inner experiences. This can have profound effects on performance, as well as wellbeing within any work environment. It is well known that the brain does not distinguish between inner and outer information in the way it responds with hormones and other chemistry (LaBerge 1990), which in turn determine physical and mental wellbeing. In other words, as controllers become aware of the tacit aspects of their experience and begin to interact directly with them, like they would in a lucid dream, they can improve their visual and other tacit structures thus improving performance. Also they can directly interact with the tacit images responsible for causing strain, like in a lucid dream, since the dynamics of tacit experience seem to be the same for work related as well as stressor imagery. Training could be instituted to enable controllers to interact with tacit content of both types which could have significant benefits for all.