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# An investigation into the visualisation of the transmission network by national grid controllers

**Lazanas, Panagiotis**

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# AN INVESTIGATION INTO THE VISUALISATION OF THE TRANSMISSION NETWORK BY NATIONAL GRID CONTROLLERS

**Panagiotis Lazanas**

A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Master of Science in Engineering.

**Johannesburg, 2005**

## DECLARATION

I declare that this dissertation is my own work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

_____.
(Signature of candidate)

____. day of _____. 2005

# ABSTRACT

**The South African electrical utility, ESKOM, is one of the largest in the world with 40 GW capacity, worth R 965 billion, and an annual income of R 33 billion. The people responsible for the voltage control of the ESKOM transmission grid are highly skilled voltage controllers. An investigation was conducted to identify what constitutes their expertise.**

**This is a multidisciplinary research project that incorporates the fields of Power System Engineering, Industrial and Cognitive Psychology and Neuro-Linguistic Programming.**
**Observations of the voltage controllers at work were carried out followed by in-depth interviews in order to identify, their Mental Control Strategies, Power System Visualization techniques, and Mental Models. Expert and novice voltage controllers were included in the research as well as one in-house Man Machine Interface (MMI) developer.**

**Some of the main findings are:**

- **The sophisticated mental strategies that allow controllers to simplify the overabundance of data presented to them.**

- **The subconsciously created vivid mental imagery that they use to make fast intuitive decisions.**

**Having obtained the above information, MMI design and human controller training can be optimised.**



**Key Words: Power System Visualization, Mental Models, Power System Operation, Operator Mental Models, Cognitive Systems Engineering.**

## ACKNOWLEDGEMENTS

**This is a multidisciplinary research project involving the fields of Electrical Engineering, Industrial Psychology, and Neuro-Linguistic Programming. I wish to express my sincere thanks to: my supervisor Prof. B Dwolatzky for all his encouragement and for offering me the research project; Dr A Thatcher for his invaluable guidance in helping me navigate the Industrial Psychology ocean; the ESKOM staff at NCC for their hospitality and cooperation, without them this research would not have materialized; the ESKOM TESP fund that provided all the necessary funding; Johan Fouché, the head of School for Electrical Engineering at TWR, for his patience and support; and all of my NLP mentors from 1994 until now for introducing me to the wondrous world of the inner mind.**

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# GLOSSARY

**Controller:** A human being responsible for controlling certain aspects of the performance of a Power Transmission Network.

**EVC:** Expert Voltage Controller.

**LDC**: Loading Desk Controller.

**Mental Model**: The Mental Model theory of Johnson–Laird (1978, 1983) [61], refers to how people create mental imagery to interpret and evaluate syllogisms. The term is also used in a broader sense to indicate mental constructs that people use to interpret events in the "world".
A mental model is a cognitive mechanism [81], for representing and making inferences about a system or problem. A mental model represents the structure and internal relationships of a system in a dynamic way. It exists in the user's mind as opposed to a conceptual model given to a user by a designer or trainer.

**MMI:** Man Machine Interface.

**MMID**: Man Machine Interface Developer.

**Modalities**: The five main senses; visual; auditory; kinaesthetic; olfactory; gustatory.

**NCC**: National Control Centre.

**NFC**: Novice Female Controller.

**NLP**: Neuro-Linguistic Programming.

**NVC**: Novice Voltage Controllers.

**PDP**: Parallel Distributed Processing.

**PSAT**: Power System Analysis Tool.

**PTDF**: Power Transfer Distribution Factors.

**SA**: Senior Advisor. An expert controller that has gone through all the stages of training has performed at a very high competence level and has many years of experience.

**Sub-modalities**: Sub-divisions of sensory experience i.e. for the visual modality some sub-modalities would be: brightness; focus; colour, distance of the mental image etc. (similarly for the other senses).

**TCD**: Transmission control desk.

**TDC**: Transmission Desk Controller.

**VPA**: Verbal Protocol Analysis.

**VCD**: Voltage control desk.

# FOREWORD

**The format of this Masters Dissertation consists of a short body (in which is included a technical paper) and a number of appendices. This is referred to as the "Paper Model" format. The technical paper presents a condensed view of the core of the research while the appendices contain the full detail of the work.**

As indicated in the **abstract** this research concerns itself with the mental strategies and visualizations that transmission grid controllers use in their work.

This is followed by **a brief introduction**, in which a number of quotes and other material introduce to the reader to concepts about how the mind works and what expertise is.
Then, a broad picture is presented which illustrates how the need for training is said to have arisen. The reader is then introduced to the South African landscape and finally introduced to the ESKOM National Control Centre. At the end of the introduction the purpose of the research is stated.

The next item is the **research paper**, with the same title as the dissertation, which contains the essence of the research project in brief.

Following that, is a section that includes all the **conclusions, recommendations, and future research**. The conclusions section shows a summary of the various mental strategies and visualization techniques used by the subjects of the investigation. Next, the research questions and other industry needs are addressed. These are followed by a list of recommendations for the improvement of the NCC working environment; followed by a list of cognitive interventions, which could be introduced in order to facilitate skills transfer within the NCC. The section ends with future research suggestions, which propose that a systems theory view of the NCC be investigated.

A complete **set of references**, of the reviewed material, which was used in the four literature reviews, is presented in the following section. Because of the multidisciplinary nature of this research four areas are reviewed: Power System Visualization; Industrial Psychology; Cognitive Psychology; and Neuro-Linguistic Programming. Other areas of interest covered in the bibliography are systems theory; general semantics; and hypnosis theory and application.

The sections mentioned above cover the first part of the dissertation. In these sections are found all the main points of the research in a consolidated form.

The appendices that follow represent the detailed material from which the previous sections were extracted. There are five appendices:

**Appendix A** contains:

- The literature review findings of the four fields reviewed, in detail. The conclusion drawn from the reviews is that the proposed research has never been done before.

**Appendix B** contains:

- A description of the NCC elements that pertain to the investigation: such as the control room layout; and the functions of the controllers who work there.
- A list of difficulties that form the foundation of the research questions.
- The research questions.

**Appendix C** contains:

- A methodology overview of the research.
- The methodology used in conducting the interviews with the controllers, by means of which their mental strategies and visualizations were elicited.

Appendix D **includes the detailed findings from the video-recorded interviews; they are clustered in three categories:**

- Controllers working on a network simulator under contingency conditions. **The controllers' behaviours** were noted and commented upon.
- Those parts of the interviews, which were conducted in order to elicit **the controllers' control strategies**. The control strategies are mental and physical action sequences, which the controllers use when they work. Comparisons were drawn between the strategies of the experienced and the not so experienced controllers.
- The parts of the interviews, which were conducted in order to elicit **the visualizations** that the controllers' use. The controllers use visualizations in order to depict the ESKOM transmission network in their minds. The various ways in which the participants can visualize the network are listed and comparisons are drawn.

**Appendix E** is very similar to the Conclusions and Recommendations section except that it contains more detail.

# INTRODUCTION

The modern Power System is the largest "machine" on earth. In the continent of Africa there are a number of interconnected Power Systems. One of these Interconnected Power Systems is the Southern African Power Pool.
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 consumer of electrical energy in 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 R 32.8 billion, with total assets of R 965 billion, 28938 employees, and serves 3.5 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.

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. This equipment is exposed to weather conditions that include temperatures of over $40^0$ C, snow, ice, gale force winds and coastal corrosion, lightning (one of the highest levels in the world) storms, and fires. A single serious incident that occurred in the Natal region generated over 2670 alarms.
The cost of partial or total blackouts is in the order of billions of rand. The 2003 blackouts in the USA and Canada cost between $ 4-6 billion.
In order to operate the ESKOM transmission network a number of human controllers work in twelve-hour shifts at the National Control Centre (NCC), at Simmerpan near Johannesburg.

This research was conducted in order to identify the mental representations, which the controllers working at the National Control Centre, use in order to control the

National Transmission Grid. The interaction and content of their mental representations, or mental models, is what makes them the experts that they are. The implications of having this information are of great significance, since the controllers play a most critical role in the ongoing and safe operation of the national grid.

The human controller is a critical link in the Power System chain and therefore his / her abilities, observable and mental, need to be identified so that:

- These abilities can be further refined;
- The mental adaptations required to use new network computer-interface equipment can be facilitated; and
- Newcomers can be trained into the field of Power System Control.

In order to meet the objectives of this research a number of disciplines were combined, they are Power Engineering; Industrial Psychology; Cognitive Psychology and Neuro-Linguistic Programming. As shown in the literature review this type of research has not been conducted anywhere in the world.

What follows is a progression of ideas that starts with the Cognitive Psychology view of how the human mind works and leads all the way to the practical reality of the ESKOM control room.

In his book "How the Mind Works" [60] Massachusetts Institute of Technology Professor of Psychology Stephen Pinker states:
"…we don't understand how the mind works- not nearly as well as we understand how the body works… however dozens of mysteries of the mind, from mental images to romantic love have been upgraded to problems." [60-p ix].
He continues: "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 fleshed this idea out by noting that intelligence consists of specifying a goal, assessing the current situation to see how it differs from the goal, and applying a set of operations that reduce the difference. We have desires, and we pursue them using beliefs (or mental models), which when all goes well, are at least approximately or probabilistically true. The old theory of stimulus and response has been proven wrong. **We act because we believe things are in a certain way and we want them to be in another**." [60-p 62]

**"The computational theory of the mind has quietly entrenched itself in neuroscience**, the study of the physiology of the brain and nervous system.
The blossoming (of the field) came from a central agenda for psychology set by the computational theory: discovering **the form of mental representations (the symbol inscriptions used by the mind) and the processes (the "demons") that access them**. This approach is similar to Plato's analogy of the cave. **The information in an internal representation is all that we CAN know about the world."** [60-p 83]

"Pinning down mental representations is the route to rigor in psychology.
**The way people generalize is perhaps the most telltale sign that the mind uses mental representations, and lots of them."** [60-p 85]

By giving various examples Pinker shows how we can know that **our mind contains mental representations specific to abstract entries for words,** not just the shapes of the words as they are printed.

Similarly in his book "The Fifth Discipline" [77], Peter Senge quotes from Howard Gardner's book "The Minds New Science": "To my mind **the major accomplishment of cognitive science** has been the clear demonstration of …**a level of mental representation**".
Senge continues to state that **our "mental models" determine not only how we make sense of the world but also how we take action**. He also quotes Harvard University's Chris Argyris (who has worked with mental models and organizational learning for thirty years): "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)**" [77-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**. When beliefs are taken as truths about the world at large." [77-p 176].

As early as 1930 Alfred Korzybski [76] stated that "**the map is not the territory**" referring to the fact that what we know of the world is never the world itself. Senge gives numerous examples where mental models have not been recognized as such and have been confused with reality. Examples are given of old mental models reasserting themselves as reality, through inertia even when new information makes them obsolete, with disastrous consequences for large industrial and business corporations.
The opposite is true as well, where the recognition of the mental models held by key decision makers, and the ability to influence them in a way that keeps up with the times has given companies a great competitive advantage.
Gregory Bateson [67], also recognized the fact that the construction of mental models is the best we can do to represent the world and interact with it. He speaks of "**the pattern that connects**" in other words **the internal representational patterns in the brain that we use to encode the world experience.**

Further, a well accepted [55-p 24] model of learning is that it takes place through the stages of Unconscious Incompetence, Conscious Incompetence, Conscious Competence, Unconscious Competence (particularly associated with expert performance) and sometimes on to the state of Unconscious / Conscious Competence

(as in the cases of experts that can teach their expertise to others). In the context of mental models, this means that first we are not aware of the absence of the mental representations of certain things or processes; then we do become aware of it; this is followed by our trying to incorporate or create such mental models within ourselves, up to the point where the mental models pass over into the other than conscious mind from where they run automatically.

**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 does not require physical prowess.

During the Second World War when the majority of expert workers left the United States for the warfront, what remained behind was a mostly unskilled workforce. It has been suggested that the need for training, as opposed to apprenticeship or prolonged theoretical studies, arose then for the first time in history. In factory production lines, tasks were broken down into small parts in order to be followed until mastered, by the unskilled work force in the absence of expert role models. In this respect, what took many years of apprenticeship to acquire was achieved in much shorter periods. Some argue that this can be achieved with complex performance as well, even with expertise that is mostly cognitive and hidden. Neuro-Linguistic Programming pioneers, R Bandler and J Grinder, have shown that it is possible to model cognitive and emotional expertise [46 – 61].

**In the current South African context**, and for different reasons, **the same urgent need for training has arisen**. Previously disadvantaged people wish to be rapidly integrated into the skilled work force and to rise to expert levels of ability and performance. This desire for rapid increase in expertise is met with the cliché that what is required is suitable practical experience in terms of time spent with experts in the field, over long periods. This impasse frustrates experts and novices alike. The former, because they hold the belief that since that is the way in which they acquired expertise, it must follow that they are right (a possible case where a mental model or belief is mistaken for reality). The latter, on the other hand, assert that not all that can be done is done to train them actively. They are opposed to passively waiting to somehow acquire the desired skills as their predecessors did. Cognitive skill acquisition therefore, unlike information transfer, remains elusive.

**The word "expertise" is a nominalization for large and complex 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" can be duplicated and "trained into" other people. 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.**

One such environment, in which the experts possess mostly internal cognitive skills, is the ESKOM National Control Centre (NCC) at Simmerpan. In this environment both experts and novices experience the above-mentioned frustrations. **It is the aim of this research to reveal some of the mental models held by the different categories of controllers (experts and novices).** These mental models will be presented in terms of content, structure, and operation. The scope of the research is to probe beyond the level of data and information to the levels of information processing, visualization, mental operational strategies, and internal decision-making criteria.
Once the mental models have been identified, then, by means of comparisons, strategies for training and other interventions can be designed as part of future work.

# AN INVESTIGATION INTO THE VISUALISATION OF THE TRANSMISSION NETWORK BY NATIONAL GRID CONTROLLERS.

**P. Lazanas**
University of the Witwatersrand, Johannesburg.

## ABSTRACT

The South African electrical utility, ESKOM, is one of the largest in the world with 40 GW capacity, worth R 965 billion, and an annual income of R 33 billion. The people responsible for the voltage control of the ESKOM transmission grid are highly skilled voltage controllers. An investigation was conducted to identify what constitutes their expertise.
This is a multidisciplinary research project that incorporates the fields of Power System Engineering, Industrial and Cognitive Psychology and Neuro-Linguistic Programming.
Observations of the voltage controllers at work were carried out followed by
in-depth interviews in order to identify, their Mental Control Strategies, Power System Visualization techniques, and Mental Models. Expert and novice voltage controllers were included in the research as well as one in-house Man Machine Interface (MMI) developer.
Some of the main findings are:

- The sophisticated mental strategies that allow controllers to simplify the overabundance of data presented to them.

- The subconsciously created vivid mental imagery that they use to make fast intuitive decisions.

Having obtained the above information MMI design and human controller training can be optimised.

## 1. INTRODUCTION

The South African electrical power grid is one of the ten largest “machines” in the world with 40 GW capacity, worth R 965 billion, and an annual income of R 33 billion. It is controlled from the national utility’s (ESKOM) control room near Johannesburg.
The ESKOM NCC comprises a circular control room in which a number of staff interact with a wide variety of computer displays and consoles. These staff members, or controllers, are responsible for the coordination of supply and demand of electrical energy, from the various centres of generation to the different load centres around South and Southern Africa. This is done via
the national grid of high voltage power lines, sub-stations etc. This network includes South Africa and links with Namibia, Zimbabwe, Botswana, Mozambique Swaziland, and Lesotho. The South African network alone has 336270 km of power lines, 150 substations, and transmission voltages of up to 765 kV.
Within the control room there are: a Transmission desk (for line maintenance scheduling, control etc.); a Loading desk (for power and frequency control); a Voltage desk (for voltage level and reactive power flow control); a Shift Manager’s desk (for overall supervision); and a number of subsidiary desks, which serve secondary functions.
Work on the Voltage desk demands the most skill, as voltage control is both complex and dynamic.
In order to carry out their duties the controllers need to have access to a variety of technical information. This includes the available capacity of generation stations, the level of power demand by load centres and its fluctuations, voltage levels at all national grid buses, reactive power flow, weather conditions and other environmental factors as well as the state of “health” of the grid. All this information is presented in a variety of ways. There are computerised displays of single line diagrams, numerical values of critical variables and various alarms, as well as information conveyed in writing, over telephones and by personal interaction.
This complex real-time flow of information has to be interpreted by the controllers. They

then make complex decisions to ensure the safe and continuous operation of the whole network, within predetermined parameters.
This research is focused on the mental interpretation of the network data, by the controllers.
Within the NCC environment, very little is known about the way(s) that controllers process information, within their minds, in order to arrive at decisions. Consequently, it is unclear what differences exist between the mental representations of the grid in the minds of experienced controllers and those with less experience.
From preliminary interviews, with senior management at NCC, a number of difficulties, which arise from the lack of this knowledge, have been identified. Symptoms of these difficulties manifest in a number of contexts. These include skills transfer and training, staff upgrading, integration between personnel and computer displays, and information gathering during operating error investigations.
The scope of the investigation presented in this paper has been limited to the Voltage Desk (which requires the most dynamic interaction between controller and network).

The research questions asked were:

- **How do the Experienced Voltage Desk Controllers do their work? What are their external behaviours while working? What are their mental representations, strategies and visualization of the network?**
- **How do the inexperienced Novice Voltage Desk controllers do the above?**
- **What are the similarities and differences between an MMI Developer and the two groups above, with respect to how they view and interact with the network?**

## 2. METHODOLOGY

1) Preliminary discussions were conducted with national control management and staff in order to get approval for the research and to establish needs. This was a complex process in an environment where interactions take place on many social and technological levels. A literature review was conducted to establish current trends in the fields of:

- **Power engineering,** to identify the current practices and considerations in the field of Power Grid Control Visualization. A number of published papers and reports were reviewed [1-13]. From these it became apparent that the term visualization is used, in this field, to describe computer display styles and data management techniques that may enable humans to reduce the time it takes them to convert data into information.
- **Industrial Psychology,** to identify elicitation methodologies. Guidance was provided by the WITS Industrial Psychology department (Dr A. J. Thatcher). The method selected was Verbal Protocol Analysis (VPA). This method has been used in previously conducted studies, in similar South African environments [14-18]. From the references listed in this paper and elsewhere an overview was obtained of the type of investigations that have been conducted into mental models and visualization, and their elicitation.
- **Cognitive Psychology**, to establish a valid theory of mental processing [19-20]. An accepted theory of how the mind works was identified which posits that unconscious processing of information is at the heart of complex decision making and visualization.
- **Neuro-Linguistic Programming**, to identify techniques that reveal the underlying representations, mental models and visualisations used by the participants [21-25]. The Metamodel process of eliciting the underlying meaning of verbal descriptions, as put forth by Dr J Grinder [21], and sub-modality elicitation [22-25], form the foundation of the interview process.

From the literature review it became clear that the investigation of the mental processing of Power Grid controllers had never been done.

2) The methodology for conducting the interviews with the controllers was formulated:

- Seven controllers were selected. Of these, two are experienced and skilled Senior Advisors (SA), two are Experienced Voltage Controllers (EVC) and two are New Voltage Controllers (NVC). The seventh is a New Female Controller (NFC) that had not yet been authorized to work on the voltage desk but was included to examine differences in perspective. She was authorized on the Loading and Transmission desks.
  An eighth person was included in the interview list. He is responsible for Man Machine Interface Design (MMID) but does not do shift-work or work in the control room itself. He was included in order to highlight any differences between control room staff and interface designers.
- Each controller was given the same task to perform on the ESKOM grid simulator. This consisted of a single 400 kV line trip, followed by a second 400 kV line trip within a few seconds, in the same area. This double contingency would normally result in a voltage collapse in the area, if left unattended.
- The controllers' performance on the simulator was video recorded. They were asked to verbally comment on what they were doing while doing it, as per VPA (Verbal Protocol Analysis) requirements.
- The video recording was then played back to them and they commented further on their activities (Retrospective VPA).
- A series of questions were asked to elicit the underlying mental representations that made their decisions possible and reveal their mental models.
- The video recordings of their performance on the simulator as well as the video recordings of the interviews were analysed to extract the material that represents the findings of this research.

3) The findings from the interviews were summarised and the relevant controller strategies and visualizations were compiled.

## 3. FINDINGS FROM THE INTERVIEWS

The findings from the interviews conducted are listed under the following headings:

- How they work (on the simulator): Observations of physiology and equipment layout during simulated contingency sessions.
- Control Strategies: What they look for and in what order during normal voltage control.
- Visualization: How they mentally process information under normal voltage control and during contingencies.

### 3.1 How They Work

The equipment used in the simulator was two TV monitors, two key-boards (one for performing switching operations and the other for selecting displays on the monitors), and a mouse.

- It was observed that **the two SAs** used both hands, one on the mouse and the other on the switching keyboard, to perform control functions (of the two, one is left handed). They remained relaxed and appeared confident sitting back in their chair. They used small hand and wrist movements in their work. They seemed to maintain an overview of their environment, working fast and anticipating contingencies. The distance between their head and the monitors was maintained at over one meter.
- **The two EVCs** also seemed calm. Their movements were slower; they both sat forward on their chair and seemed to peer into the monitors more fixedly (this may have cognitive implications of not considering the big picture as well as having a reactive rather than proactive attitude with an external locus of control). Of the two only one used both hands to work. They both leaned on their elbows and supported their chin with their left hand when not using it. Their hand movements were large and thus took longer. Their head to monitor distance was about 0.8 m. One of them was quite sensitive to the volume of the audible alarms.

- **The two NVCs** used only their right hands to work both the mouse and keyboard. Their left hands were not used at all. They appeared stiffer and more abrupt in their movements, focussing on the monitors (peering into them with similar possible cognitive consequences as the two EVCs).
  Their movements were big and abrupt / fast. They seemed to experience and display strong emotions. Their head to monitor distance was about 1m to 0.8 m for the one and 0.8 m for the other.
- **The NFC** was similar to the NVCs but was even more drawn in by the monitors, progressively moving her head closer. As the simulated contingency unfolded she seemed very worried. Her movements were big (both body and right arm). Her left hand was folded behind her back and not used at all. Her head to monitor distance varied from 0.7m to about 0.5m. She appeared sensitive to the level of audible alarms.
- **The MMID** works in an office in front of a single monitor the same size as that of the controllers' (they use two at a time), however the distance between his face and the monitor is about 0.4m.
  His ability to see the information displayed is thus better than the controllers who work from about 0.7m to over 1m away from the monitors. His work does not involve interacting with a dynamic network. Instead he is responsible for finding practical ways of converting data into information and implementing new technologies.

### 3.2 Control Strategies

In this section the control strategies, i.e. what the participants look for and in what order, were identified. This was done by creating a matrix that has a list of fifty-nine comments (from what the participants said during their interviews) on the vertical axis and the eight participants on the horizontal axis. Xs were inserted where a comment came from a particular participant. What follows is a summary of the information that emerged from the matrix. Comments that pertained to all concerned were omitted in this paper due to space constraints. They are however included in Appendix D of the dissertation with the same title.

- **The following information summary came from the two SAs and the two EVCs list of comments.**
  They have self-created, predetermined voltage range limits (per region) in order to be **proactive** in their control strategies (high voltage preset levels for high loads, or mental templates with high and low values in them used for scanning). They use simple block diagrams in their mind to isolate an area on which they work. This **"rubber banding"** is the most significant strategy step difference between the experienced and the inexperienced group. They enquire what are the causes of faults when they occur. They have got used to displays that are difficult for novices to interpret. They also have high stress thresholds.
- **The following information summary came from the SAs' list of comments.**
  They "step back" regularly to see the big picture; they use varied **proactive** strategies to control the network; they are mindful of external conditions (time of day etc.); they mentally drop useless information, and experience a range of normal, abnormal and critical emotional states, as per network conditions. They have control strategies (which include mental pictures that "show" them what to do) that get progressively simpler as contingencies get more severe. They check their decisions with the shift manager if there is time. Sometimes they may work too fast.
- **The following information summary came from the EVC s' list of comments.**
  They have a structured sequential approach to their work relying on their memory of what has happened before or instructions from the shift manager. They are aware of the consequences of their actions on plant (e.g. load shedding). They do not experience or express intense emotional states (too calm). Serious contingencies cause them to feel sharpened into alertness.

- **The following information summary came from the NVCs' list of comments.**
  In general, their mental world works against them. They create exaggerated emotions by imagining situations that are worse than reality, leading to feelings of panic (shaking, hot anxiety in the gut and confusion in the head; these limit information processing abilities), momentary blank-outs and loss of control. They need senior personnel around them to feel secure and calm under extreme contingencies. They use elaborate detailed or scenic mental images and do not "zoom out" to see the big picture. They always check with the shift manager before operating, especially under contingency conditions.
- **The following information summary came from the NFC's list of comments.**
  The NFC's work is not as urgent as that of the voltage controllers, her work has to be pre -approved. She thinks in terms of what is presented on the monitors and does not use mental models to the same extent as the VCs. She experiences low stress and reports high satisfaction in her work.
- **The following information summary came from the MMID's list of comments.**
  The MMID also works in a low stress environment and reports high satisfaction from his work. He effortlessly creates complete, elaborate and varied mental images and is aware of them (unlike the others). His strategies are intended to convert data to information, by prioritising, categorising, and depicting only relevant information on the monitors (particularly alarms). He is looking to the future (five to ten years ahead) where computer networks instead of simple SCADA systems and "intelligent" information processing will be the norm. He is constrained by the fact that he is future orientated and has to "drag everyone along", as controllers tend to be reluctant to embrace changes.

**3.3 Visualization.**

This section is a very significant part of this investigation. The information presented below shows how the controllers visualize the network under different conditions. Of particular interest were the visual aspects of their mental representations.
It is well accepted that mental representations are varied and many of them are not available for conscious scrutiny. It is very important to note that all the participants were unaware of what has been documented below prior to the interview process.

- **SA1:** He has a mental page with voltage values that he uses as a template against which he compares the actual voltage display page. When there are discrepancies he feels pressure in his chest, this prompts him to act and make corrections.
  For analysis work he has the whole network in front of him (mentally). First as a ball (+/- 20 cm in diameter), then opens it out flat, in full colour, at arms length (to the size of +/- 4 $m^2$). He only looks at one Region / Area / Station at a time, as the whole is too big for him to "see" all at once.
  Under contingency conditions, he visualizes the affected areas as 2D unlabeled blocks with lines in between them (+/- 6 part image, white on grey background). He uses these simple mental images in order to decide what to do next as well as to determine the consequences of his actions.
- **SA2:** He has a small mental template with +/- 5% voltage values in it (a small block) that he runs against the voltage page values displayed on the monitor. From performing such a scan he gets either a normal, abnormal (close to 5%) or urgent feeling (over 5% difference). He has divided the voltage display page into quadrants.
  When there is a fault, he mentally sees the area involved with just a few lines and no labels (+/- 6 part image) together with a flashing red block in it, this tells him there is trouble.

He then uses operating steps that he visualizes on mental "cards". These "cards" are white (normal condition), yellow / orange (abnormal) and flashing orange (urgent). The amount of information (procedural steps to correct problems) on them gets less and less as they go from normal to urgent. He has a proactive approach and mentally discards useless information. He cross checks his decisions with the shift manager to get perspective (big picture) when there is time.

For network analysis under non-urgent conditions he uses 3D simple mental pictures in colour.

- **EVC1:** He watches the voltage page and if there is a colour change in one of the numerical voltage values or an audible alarm he knows that here is contingency. He then asks for its cause He also has simplified one-line mental diagrams of main sub stations that help him to work out how to operate.

  He works from memory of past, similar events when deciding what to do or otherwise requests instructions from a senior person.

  He uses a simple mental image; this is a block with lines (+/- 3 part image), to decide what to do. This mental diagram gets sharper with more contrast when there is trouble, this helps to focus his attention and increase the speed of his response.
- **EVC2:** He scans the voltage display page using key points and decides what needs attention (proactive).

  In contingencies he sees a "blob" representing the area with just the main lines shown (+/- 3 part image). This switches on like a light in his mind while he works and disappears when the emergency is over.

  When things return to normal he mentally sees closed breakers and MW values added to his diagram.
- **NVC1:** During the double contingency he saw red alarms flashing in his mind (more than actual number) and got an out of control feeling.

  Mental images of what the substations look like physically start to fly past in a blur and he has difficulty finding use for these pictures. He said that he is looking for a picture that will tell him what to do and if he does not find it he can't decide what to do. This leads to anxiety, confusion and unconscious actions.

  He said that he then needs someone senior around him, for support, in order to think clearly.
- **NVC2:** He has detailed mental pictures and operating strategies for each region under normal conditions.

  During the double contingency he got fixated on a capacitor bank and could not zoom out, in his mind, to see the big picture and thus know where to go next.

  He is proud of his ability to have a very comprehensive image of the network in his mind but does not yet know how to navigate that image under stress. This leads him to panic and freeze.
- **NFC:** She thinks in terms of what she sees in front of her on the monitors. Her work does not require fast analysis like the voltage control staff.

  When she saw the lines trip she thought that the voltage control person would have problems and felt alert.

  She requires confirmation of her operations by a senior person.
- **MMID:** His mental images are sparse, clean, limited in variety, with colour coordination and visually aesthetic.

  His criteria for good images are: Colour quality, and neatness.

  He can, at will, create 3D, complex images (+/- 9 parts) and metaphors that he can manipulate in mental space with ease. His visual mental capacity is very advanced.

## 4. CONCLUSIONS

It appears, that the experienced controllers work by simplifying the information that they get from the monitors by "rubber banding" the affected area and representing its key elements with about five to six parts of visual information. This allows them to deal with variety, complexity, and new events on the dynamic network by focussing, in their mind, on the essentials. This is necessary as the information presented on the monitors (under

contingencies) is far too much to absorb at once [25]. These simplified mental diagrams assist them in knowing what to do next and what will be the consequences of their actions within the affected area, as well as the areas around it. The best among them do all that proactively, by drawing on memories and by visualizing new scenarios. They often make decisions based on what "feels right" as there is very little time for analysis during contingencies.

It also seems that the new controllers are not aware of these "internal" cognitive steps, particularly the ability to zoom out mentally, that can assist them to get direction from seeing the big picture.

On the surface the MMID's strategies are in keeping with the controllers' requirements. However his images (also neat and simple) do not match the ones that they use. To that extent they are not keen to accept them because they don't fit in with what they have "programmed" in their minds. This may be part of what creates the perception that controllers are opposed to new things and change. On their side they say that changes "feel wrong" and that they take time to get used to. They experience this as stress, because of the potential consequences that may take place in the transition period, for which they will be held responsible.

Finally the hidden competencies that are the very foundation of expertise in the control room have, until now, remained vague and invisible. This served to perpetuate the perception, in some minds, that the controllers' job is of a lower grade than that of system engineers. This view is incorrect. Their skill lies in being able to integrate the state of the whole of the network over long periods of calm followed by contingencies, which are rare. Contingencies demand instant responses, which may have grave consequences.

## 5. RECOMMENDATIONS

The controllers' work conditions vary between long hours of inactivity, followed by moderate activity at load pick up and drop off times and short bursts of "panic" when contingencies take place (seldom).

From the above observations as well as discussions with the participants the following recommendations are put forth:

- Training for two-hand operation should be encouraged for reasons of speed and whole brain function.
- The implications of head distance from the monitors should be investigated further (input from ophthalmologists and ergonomic experts should be considered).
- The intense gazing into the monitors to obtain information should be balanced by the accessing of the controllers' own internal representations. This may facilitate anticipation of events and a proactive operating style.
- All members of a shift should train together in the simulator room.
- More screens should be made available to display information as per individual controller preferences.
- Audible alarms could be made more varied in tone, to distinguish between different types. Their sound level should be adjustable to meet individual needs.
- The layout of the workstations should be tailored to individual preferences to facilitate speed and instinctive movement patterns.
- The size of font used for identifying the name of a substation, followed by a feeder name and a power line number is quite small (particularly if you sit far from the monitors). Also this information is displayed at the top of the screen away from the schematic representation of the network. These two shortcomings should be addressed, as they are part of the main causes of operating errors.
- Chairs that fit the controllers should be allocated to them individually as they work twelve-hour shifts.
- Opportunities should be made available for video recording of simulator sessions. These can be played back to the controllers in order for them to learn from observing their own behaviours, working individually and as a member of a shift. This last recommendation is of particular significance as it will increase self and group interaction awareness (a very important factor in the control room).

- A number of cognitive training interventions (no cognitive training is taking place at present) can be introduced to address all the differences revealed (in strategy as well as visualization) between the experienced and new controllers. This can also be done with all staff upgrading.
- Computer display design can be done in such a way as to take into account the mental requirements of the end users. The simulator can be used to tailor such designs.

Investigations of operating errors should consider the fact that actions originate in the minds of controllers. Their mental "behaviours" can now be noted and suitable training and ergonomic changes, to address cognitive shortcomings (Perky effect), should be introduced.

## 6. FUTURE RESEARCH

Another issue revealed in the investigation was that emotional states play a major role in the control room environment. Equally critical are the relationships between the various members of a shift. These aspects of control room life will form the theme of another paper stemming from the current investigation.

Another important issue is that it is incorrect to speak in terms of "controllers" as if they stand apart from the network and control it. This is far from the truth, as the experienced controllers identify with the network as part of themselves (this forms part of their expertise). **It is far closer to the truth, to state that the network, the MMI, the individual controller as well as every member of a shift and NCC management, even the controllers' family members, all form a system.** This system has partts, which affect each other with varying time constants and multiple layers of physical, mental, emotional, and technical interactions. This systemic view warrants further research as we move towards more complex scenarios and larger networks.

It is my opinion that the above should be considered, if not before, at least together with MMI designs from vendors that present their systems for controllers to "fit into". MMI systems can then be engineered for greater integration.

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Panos Lazanas received the B-Tech degree in Electrical Engineering from the Witwatersrand Technikon, Johannesburg. He is a registered Professional Technologist with the Engineering Council of South Africa. He currently holds the post of Head of Department for Power Engineering at the Witwatersrand Technikon. He is also a registered International NLP trainer with an interest in NLP application in education and has presented papers at international conferences in that field. At present he is conducting research towards an MSc in Electrical Engineering for Power System Visualization.

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# CONCLUSIONS, RECOMMENDATIONS, AND FUTURE RESEARCH

## 1. CONCLUSIONS

It appears that experienced controllers work by simplifying the information that they obtain from the monitors by "rubber banding" (mentally focus on and isolate) the affected area. They mentally represent the key elements of that area in about five to seven (see Pinker [60]) parts of information. This allows them to deal with variety, complexity, and new events on the dynamic network by focussing on the perceived essentials. This is necessary, because the information presented on the monitors is far too extensive to absorb at once consciously (see the 7+/- 2 parts of conscious information limit [56 & 60]). This is particularly true during contingencies where the simultaneously displayed alarms can run into thousands. The simplified mental diagrams that the controllers employ, assist them in deciding on what action to take and what the consequences of their actions will be within the affected area, as well as the areas around it. The best among them do all of this proactively by drawing on memories and by visualizing new scenarios.

It seems that the new controllers are not aware of these "internal" cognitive steps, in particular the ability to zoom out mentally to get direction from seeing the big picture. They are now aware of the absence of this ability.

The MMID's strategies are in keeping with the controllers' requirements. However his images (also neat and simple) do not match those that they use. To this extent they are not keen to accept them because they don't correspond with what they have "programmed" in their minds. This may be part of what creates the perception that controllers are opposed to change. The controllers say that changes "feel wrong" and that it takes time to get used to them. They experience this as stress, because of the potential consequences that may take place during the transition period, for which they will be held responsible.

The hidden competencies that are the very foundation of expertise in the control room have, until now, remained vague and invisible. This served to perpetuate the perception, in some minds, that the controllers' job is of a lower grade than that of system engineers. This view is totally incorrect, as their skill lies in being able to mentally integrate the entire network, during long periods of calm followed by contingencies, which are rare and demand instant responses, which may have grave consequences.
It can be shown that most of the original difficulties, which were identified during the first series of discussions with senior management at NCC (see Appendix B), have been addressed (see Appendix E).

## 2. RECOMMENDATIONS

The list of recommendations below is an abridged version of a more expanded one shown in Appendix E

### Recommendations from the simulator work observations.

After reviewing the simulator work video-recordings; observing the controllers at work in the control room itself (on separate occasions); and having discussions with them, the following recommendations are put forth:

1. **Training for two-hand operation of the keyboards and the mouse should be encouraged.**

2. **The controllers should consider alternatives, with respect to computer monitor position, height, distance, tilt, and colours used for the displays.**

3. **Intensely gazing into the screens, should be balanced by the accessing of the controllers' internal representations.**

4. **Shifts (comprising of about five members) should train together in the simulator.**

5. **More screens could be made available to display information as per individual controller preferences.**

6. **Audible alarms could be made more varied in tone.**

7. **The layout of the workstations should be tailored to individual preferences.**

8. **The fonts used to present written information on the computer monitors should be made larger. Written information should be placed on the grid schematic diagrams.**

9. **Chairs that fit individual controllers should be obtained.**

10. **More opportunities should be created for video recorded simulator sessions.**

## Recommendations from the review of the working strategies and visualization sections.

1. Best practices should be identified and collated so that novices can adopt what suits them from various options.

2. **Experienced controllers and novices should be matched for training purposes according to their internal representations.**

3. **Cognitive training interventions should be introduced.**

4. **The elicitation and formalization of the mental models and cognitive skills of experts could be one of the prerequisites for their promotion to higher levels within ESKOM.**

5. **Computer displays can be designed in such a way as to take into account the mental requirements of the end users.**

6. **Investigators of operating errors should consider the fact that actions originate in the minds of controllers.**

7. **A training program could be formulated that progressively instils, in the minds of novices, the required cognitive skills.**

8. **A new vocabulary can be created within the NCC that addresses the new mental dimensions revealed.**

9. **The controllers' real expertise is cognitive. This could be acknowledged through their performance appraisals.**

10. **Equipment upgrading processes can be facilitated by taking cognisance of the identified mental models [80].**

Finally, it is clear that a greater understanding has been reached with respect to how the experts and novices at the ESKOM NCC process information in their minds. This directly addresses the research questions. We can generalize this result further, to say that in any other control room environment the revealing of the content and structure of expert and novice mental models' can only enhance the efforts for the transfer of higher order skills. This accelerated skills transfer methodology can then be adapted to any environment in which experts and novices work together, in South Africa or elsewhere, and at all levels of corporate structure.

## 3. FUTURE RESEARCH

Emotional states play a major role in the control room environment. Equally critical are the relationships between the various members of a shift. These aspects of control room life will form the theme of another paper stemming from the current investigation.

Further, it is incorrect to speak in terms of “controllers” as if they stand apart from the network and control it. This is far from the truth. The experienced controllers regard themselves as part of the network and report to know how it “feels” (this forms part of their expertise). It is far closer to the truth to state that **the network, the MMIs, the individual controller as well as every member of a shift and NCC management, even the controllers’ family members, all form a system [80]**. This system has parts, which affect each other with varying time constants, and multiple layers of physical, mental, emotional, and technical interactions. **This systemic view warrants further research,** as we move towards more complex and larger network scenarios (see [60] p 392/3). It is my opinion that this should be considered, if not before, at least together with MMI designs from vendors that require controllers to “fit into” their systems.
MMI systems can then be engineered for greater levels of integration with the humans that use them.

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# A P P E N D I X  A

# L I T E R A T U R E  R E V I E W S

## 1. INTRODUCTION

The nature of this research is multidisciplinary, drawing from the fields of Power Engineering, Power System Operation, Industrial and Cognitive Psychology, and the modelling techniques of Neuro-Linguistic Programming.
The field of Power Engineering represents the foundation of the engineering knowledge required in order to do justice to the complexity of the national power grid. I hold my graduate degree in this area. The field of Power systems operations was reviewed first for the reasons listed below. Then the field of Industrial Psychology was included; Dr A Thatcher (from the department of Industrial Psychology at WITS University) was invaluable in pointing the way in person and through his published work. Cognitive psychology represents more of a background to the research project. Finally, the field of Neuro-Linguistic Programming was added since the very foundation of NLP is the modelling of excellence in human performance. I have many years of training in this field and have had very good results with its application in education.

Literature reviews were conducted in the fields of:

- **Power System Visualization,** to identify the current practices and considerations in the field of Power Grid Control Visualization. A number of published papers and reports were reviewed [1-19]. From these, it became apparent that in this field the term visualization is used to describe computer display styles and data management techniques that may enable humans to reduce the time it takes them to convert data into information.
- **Industrial Psychology**, to identify mental model elicitation methodologies [20-45]. The method selected was Verbal Protocol Analysis (VPA). This method has been used in previously conducted studies in similar South African environments. From the references listed in the reference section an overview was obtained as to the type of investigations that have been conducted into mental models, visualization, and their elicitation.
- **Cognitive Psychology**, to establish a valid theory of mental processing [60-63]. An accepted theory of how the mind works was identified. The theory posits, among other things, that unconscious processing of information is at the heart of complex decision-making and visualization.

- **Neuro-Linguistic Programming**, to identify techniques that reveal the underlying representations, visualisations and mental models used by the participants [46-59]. The Metamodel process of eliciting the underlying meaning of verbal descriptions, as put forth by Dr J Grinder [46], and sub-modality elicitation [50-57] form the foundation of the interview process.

From these literature reviews it became clear that the investigation of the mental processing of Power Grid controllers had never been done.

## 2. REVIEW OF THE FIELD OF POWER SYSTEM VISUALIZATION [1-19].

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. Each paper summary is labelled with a number i.e. 2.1, 2.2 etc. These numbers are not the paper reference numbers, which are shown in square brackets i.e. [1], [2], etc.

**2.1**
In a very concise summary Professor A Petroianu from the University of Cape Town lists the following Power System Elements, Operations and Techniques as pertinent to the S African environment [1].
They are presented as categories with sub-fields below.

### Power System Components

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

**Operation**

Normal Conditions
Emergency Conditions

**Control**

$f$-P Control
V-Q Control

**Optimisation**

Power Economics

**Quality Of Supply**

Power Quality

**Regulatory & Institutional Environment**

Operation under Competitive Conditions

It is within this set of elements 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 as the following papers show. It is also true, that the general approach taken by utilities around the world is one where they have handed down equipment and techniques to the controllers, to which the controllers must adapt in order to operate their respective networks.

**2.2**

In his paper "Control Centres Are Here To Stay" T E Dy-Liacco (2002) [2] states that in 1972 there were about 10 Energy Management Centres in the world. This number has grown to 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.

**2.3**

Following on the theme of the increase of demands made on Control Centres (CC),
L Bainbridge (industrial psychologist) in an article titled "Study of Real-time Human Decision-making using a Plant Simulator" [3] 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.
As the author very aptly puts it "…controllers do not want information on the control panel they want it in their heads".

**2.4**
In an article entitled "Stretching the Limits of Power System Analysis" L V Mitsche [4] lists the power system phenomena that CC 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 the simulation tools that can be used to address them, as follows:

**Table A1.** Power System Phenomena, available Power System Controls, and appropriate Simulation Tools.

| **Power System Phenomena** | **Power System Controls** | **Simulation Tools** |
|---|---|---|
| **Surges** ($10^{-4}$ to 0.1 s) | HVDC, SVC, GENERATION CONTROL | SURGE S/WARE |
| **Power Swings** (0.01 to 10 s) | PR. MOVER & GEN. CONTROL Low Frequency Control (LFC) | DYNAMIC SIMULATIONS |
| **Frequency Variations**(10 s to 1 hr) | PR. MOVER CONTROL, LFC, CONTROLLER ACTIONS | & POWER FLOW& OPT. P/FLOW |
| **Economics** (5 min to 1 day) | PR. MOVER CONTROL, LFC CONTROLLER ACTIONS | & SECURITY CONSTRAINED OPTIMIZATION |
| **Operations Planning** (1 hr to over 1 year) | PR. MOVER CONTROL, LFC, CONTROLLER ACTIONS, & SYSTEM REINFORCEMENT | & UNIT COMMITMENT & PRODUCTION SIMULATION |
| **Planning** (months to years) | SYSTEM REINFORCEMENT | & RELIABILITY |

It is pointed out in the paper that the trend is for more powerful computers doing more and more data processing. The results are presented to less experienced engineers that have neither the time nor the background for traditional case preparation or analysis.

The writer makes a strong case for filling in the data where information “gaps” exist. This means that data preparation, case selection, and most important results analysis, must be carried out by the invention and development of progressively more sophisticated human machine interfaces.

**2.5**

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 [5], provided the perspective on the way that computers have being 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 result of that are the energy management systems that we have today (G W Stagg) [5].
In those days there was great opposition to digital load flow programs as analogue methods “seemed” more natural.
The list of contributors to the field is long and impressive.
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 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 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 (M Abibi) [5].

Similarly in Europe, since 1962, Power System Computation Conferences (PSCC) have been held. 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.
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 (M Laughton) [5]. Although not extinct at present (2003) power engineers are in short supply. This further supports the case for computer assisted network control, as it appears that the interest in Power Engineering studies is not on the increase.
Coming back to computers [5], early algorithms using 100 words of memory were considered "appalling" and all that was analysed was transient and steady state stability. Now (1993) we have short term, medium and long-term stability, angular stability, voltage stability and we use Eigenvalue 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 (J E Van Ness) [5].
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.

**2.6**

The creation of hierarchical clustering within power networks is one emerging trend to facilitate the visualization of the complexity of the networks.
In a report on "Human Factors Review of Electric Power Dispatch Control Centres" (1982) commissioned by the Electric Power Research Institute (EPRI) [6], the information requirements of the controller, for normal as well as emergency network operation, were identified and evaluated.
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-despatch, Dispatch and Post-dispatch, to system states of Normal, Degraded and Restorative.
In addition to these, the study 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.
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.
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 stress levels, up to a point where it abruptly dropped to below acceptable. 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. The issue of stress is a great factor that should not be underestimated.

The significant parameters of time lines of the control system are:

- 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.

- 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 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.

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 thought process. 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 minimise the disruptive effect.

Another issue is the control system availability, not just its time response. A cost / benefit ratio can reveal the need for backup equipment and procedures.
A number of desirable controller aptitudes and training objectives have been listed, with particular emphasis on stress (managing and reduction) and the use of simulators in general.

In conclusion, the report states that at present (1982), controllers are not being presented with all the information that they need. Instead, a large volume of raw data is provided which is not converted into useful information on time.
A list of **13 proposed recommendations** follows, these would go a long way towards addressing all the abovementioned shortcomings. They are:

1) Develop and present more transformed data (from data to information).

2) Present this information in varying time domains as per system state and operating conditions.

3) It is to be accepted that controllers require information in a way that will aid them in restoring the system to its normal state.

4) The overabundance of raw data during degraded power system states should be reduced.

5) The controller should be informed of significant changes and their consequences at a higher level of priority.

6) Dynamic methods of detection, utilization and display of power system abnormal operating states, should be implemented in application software and in warning systems.

7) Overall integrity of system communications should be displayed to increase confidence in decision-making.

8) The priority of system state information provided, should be based on the levels of power system states.

9) Post-dispatch functions (logs, reports, etc.) should be automated.

10) Alarms should be dynamically prioritised and only displayed at stations where they are of value.

11) 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).

12) Predictive algorithms should be utilised for State Estimation, Power Flow, Contingency Analysis, and Preventive Actions.

13) Load shedding and similar operations should be automated based on system performance.

**2.7**

The paper "Assessing the Impact of Computer Workload on Operator Stress: The Role of System Controllability" (1989) [7] acknowledges the role of stress as a function of how difficult it is to control a system via computer interfaces. This is because of the cognitive demands and more intrinsic control (planning, decision-making) requirements placed on controllers by the system as well as the interface itself.

**2.8**

In the paper "The Man Machine Interface in Electrical Generating Plant Control – The Ergonomic Design of Majuba Power Station Unit Control Room" by P H Knothe (1989) [8], it is stated that **"insight into the nature and behavioural 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.**

The ergonomic considerations of control room design include:

- Anatomy
- Physiology
- Sensory Physiology
- Psychology

The following aspects should be considered within the control room environment:

1) Condensing of large data sets.
2) Functional relationships should be considered over spatial ones in plant modelling

3) Grouping of information displays with relevant controls, to reduce risk of incorrect operations.
4) Arrange control interfaces according to operator instinctive reactions during emergency conditions rather than his / her cognitive reactions.
5) Standardise displays and controls to avoid errors due to expectancy.
6) Differentiate displays in various levels in terms of importance, function, and criticality.
7) Minimise the controllers' visual scan, reach and walking requirements.
8) Arrange control areas according to medium (steam, etc.) or energy flow.
9) Ensure an integrated approach to the display of alarms and data.

The paper 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 and people get used to what they have, perceiving changes in a suspicious way. It is recommended that more input be obtained from the human engineering sciences.

**2.9**

In the paper "Envisioning Power System Data: Concepts and a Prototype System State Representation" (1992) P M Mahadev and R D Christie [9] present an overview, of the state-of-the-art at the time, of Man Machine Interfacing and Power Network Visualization.

They state that existing representational methods mostly present large sets of numerical data, which then has 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.).

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 controllers work becomes easier and faster.

The table below shows 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)**

| **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 |

The paper starts by identifying the shortcomings of the available visualisation tools of the time, given that these tools are used in three ways:

- **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", this is a quote from Hamming [9, [1]].
The reasons that human controllers have difficulty in using numerical data representation are as follows:
Conscious processing normally can take place with a maximum of 7 +/- 2 bits of information (G Miller 1956, [55-p 267]) thus making large numerical data sets difficult to use.
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.

| **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, existing unsuitable practises include:

- **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 abovementioned 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).

**The ideal representation would be a physical realisation of the mental image, of the network that people create, after scrutinising and integrating a multitude of data.**

The case is made that geographical representation of the network is preferred, since it makes use of the natural ability of humans to remember and reason about geographical data. Power flow in lines is depicted as shown below, where the width of the light grey rectangle is proportional to power flow magnitude. For overloaded lines the light grey rectangle outline is highlighted.
Vertical boxes that fill up from the bottom as voltages increase represent bus voltages.




**Fig. A1.** Sample Power Flow Lines and Bus Voltage Boxes.

The paper concludes by stating that the above methodology will be presented to network controllers so that they can offer comments as to its suitability in meeting their needs.

The information presented in this paper was later (April 1994) submitted in the form of an EPRI report with the heading “Visualizing Power System Data” [10].

**2.10**

H Mitsui and RD Christie further developed some of the above concepts in a paper in 1997. The title of the paper is “Visualizing Voltage Profiles for Large Scale Power Systems” [11].

Here the authors 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 realization of the available graphics display potential in power system control centres.

**2.11**

In their paper “Envisioning Power System Data: Vulnerability and Severity Representations for Static Security Assessment” P M Mahadev and R D Christie [12] discuss the development of graphical representations for a global display of power system security states for sets of contingencies.

The main premise of the paper 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.

The visualization (by means of computer displays) strategies discussed essentially convey information about two key concepts.

- How the loss of one element affects the rest of the system, i.e. the severity of the loss of each element, and
- How each element of the power system is affected by the contingency set, i.e. the vulnerability of that element.

These two different aspects of security require two different representations and some simple user interface to move between them.

The key benefit of the methods proposed is that the results of severity and vulnerability analyses for an entire contingency set are displayed on one page in a geographic context.

On-line security assessment was typically dealt with in two stages, when software speed was a limitation. That is, each contingency case was ranked depending on the severity of its impact on the network and then a full power flow was conducted for the most severe ones.
Computer speed developments are now such that whole sets of contingency evaluations can be conducted in very short times. The paradoxical consequence of this however, is that the amount of numerical data generated from such solutions is practically unusable in practical time frames.
The only way forward then, is to aggregate data in one form or another so that, at a glance, the network can be viewed with all its main vulnerable parts highlighted. Together with this the relative contingency severity should be displayed and assessed.

Originally there were three main methods for doing this.

- The use of security indices that rank contingencies. The main drawback being the loss of problem detail, such as which elements have exceeded limits or how the compounded affect was reached.
- Limit checking and display of violations as alarms, is another method. Again, the number of alarms that increase during a severe contingency makes this approach less than ideal. This is because of a phenomenon referred to as masking, in which important violations can be obscured by les important ones.
- A third option, is the classification of security state indications as Normal, Emergency, Restorative and Alert. This method too suffers from information overload and masking problems.

A one-line display of an Energy Management System (EMS) for communicating security information contains too many numbers on the display. The limited use of graphics and colour, to indicate circuit breaker states etc., does not help to produce clarity during severe contingency states. The problem is further compounded by the degree of display manipulation required.
The paper thus makes the case that only the graphical representation of aggregated power flow results is capable of meeting the requirements of controllers. What they require is the assessment and comprehension “at a glance”, of the severity of the loss and the vulnerability of the elements of a total network under contingency conditions.

In this respect, the severity of an outage (which outages cause the worst problems) is assessed for all the lines and buses by means of the relevant Performance Index (PI, as defined in the paper) and then shown in graphic form, on a one-page display.
PIs can be combined to get a total severity index for a particular contingency case.
Vulnerability (the sum of an element’s PIs over a set of contingency cases) is then considered, calculated, and displayed on a separate display page.

The proposed method uses 2D displays. 3D displays distort the relative importance of displayed information by showing lines and bus information at the back of the visual field as smaller. This may create the impression that what is shown at the back is less important.

For power lines vulnerability and severity are encoded as line width, which together with line length results in a larger area displayed. This ties up well with the fact that, generally, longer lines are more important.
Buses are depicted as hollow boxes filled up from the bottom, as the vulnerability and severity indices increase for the particular bus.
The result is such that on the severity display page, clicking on an element of the network (bus or line) creates a contingency display one-line diagram with the chosen element outaged. The rest of the elements are displayed with varying line widths or filled up boxes depending on the degree of severity that they experience.
Clicking an element on the vulnerability display highlights all the other elements whose outage would cause a violation on the chosen element.

The displays were implemented in X-Windows with X-toolkit Athena widgets and have been run on both Sun and HP workstations.
Data for the severity and vulnerability representations is obtained from the complete contingency evaluation of all generator and transmission line outages using AC power flow. The severity and vulnerability indices are calculated based on the equations listed in the paper. The display is fast, effective and is not colour dependant (thus colours can be overlaid for alarms, voltage status etc.).

A post-contingency system state representation display page allows for a view of line flows and bus voltages after the contingency has occurred. This display makes use of the methods discussed in a previous paper entitled “Envisioning Power System Data: Concepts and a Prototype System State Representation” of 1992, [9].
In conclusion the authors state that the above methods need to be evaluated by the relevant network controllers to ensure their relevance to their task of practically running the network.

**2.12**
In another paper with the title “Minimizing User Interaction in Energy Management Systems: Task Adaptive Visualization” (TAV) (1996) [13], Mahadev P. M. and Christie R. D. point out that any effort exerted by controllers that does not change the power system is “overhead”. As a result a good User Interface (UI) should reduce such effort to a minimum. The TAV approach is centred on the concept of “Show me what I need to see” and therefore some form of decision-making by 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 windows etc. This is not an improvement in overall efficiency compared to the traditional Character Graphics User Interface (CGUI).

Instead the UI should be task orientated 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. High-level control actions, where one task requires one action, to operate the network would be regarded as an additional improvement.
In the paper a four-step TAV method is used as an example to correct a line overload contingency. The paper concludes with comments for further application.

**2.13**
In his papers entitled "New Methods for the Visualization of Electric Power System Information" [14] and "New Techniques for Power System Visualization Under Deregulation" [15], T J Overbye presents the latest (2000) offerings in the field of network visualization /representation. These two papers are very similar.
What is particularly interesting, is that he introduces new reasons why sophisticated, multi-layered and interactive power system representation technology, is increasingly becoming a necessity, rather than a "nice to have" option. Since 1992, in the USA, a free market approach has been introduced to the delivery of electric power. This means that controllers will now have to carry the added responsibility, of facilitating power flow distribution according to pricing demands, instead of just applying engineering considerations to run the network, as in years gone by.
This means, that without compromising network safety, they will have to make decisions as to how power flow is routed through the network so as to meet "orders" based on pricing. Often, the laws of physics that the grid obeys are at odds with the artificial rules imposed on the grid in order to facilitate competitive markets. This has already resulted in network elements overloading (a transmission line and a transformer in the mid-west in 1998). The result was that electricity spot market prices soared to threefold their normal values, in some States, causing utilities great financial losses as their prices to consumers are fixed [15].
This was the result of loop flow due to circuit constraints, which led to equipment overload, which in turn prevented further supply of power, that led to the price hike which lasted for some days.
Due to the possibility of this situation arising again, network controller's decisions will come under increased scrutiny as they can have severe financial impact.

The visualisation methods introduced by the paper [14] are:

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

Animation of power flow values, refers to the use of arrows along the length of power lines that are animated, using animation rates of ten times per second. This

approach brings the display to life. Initially only a small number of voltage busses is shown and a zoom /pan function allows navigation of the network.
Another option is to use dynamically sized pie charts that indicate the percentage loading of lines. A magnification factor is introduced, so that when a line load exceeds a given percentage, the pie chart associated with that line is magnified, by an increasing amount proportional to the line loading (a factor of 5 at 70%, a factor of 7 at 80%, etc.).

The above techniques, however, run into difficulties when large numbers of busses are displayed. To overcome this problem another method has been devised, namely contouring.
Contours are particularly useful in revealing patterns and trends in the network at a glance. Since current and voltage values are normally measured at busses, virtual values (weighted averages of voltage and % line loading) are used along line lengths. Typically, red was used for higher values and blue for lower than stipulated voltage values. This choice of colours was later proven to be counterintuitive foe the controllers that tried out the visualization tool.
Overall this method is particularly suited for spot price representations rather than the display of electrical quantities.

When considering the ability of the network to accommodate additional power transfers (Available Transmission Capacity or ATC), aggregation of power system data can be used.
This is done with use of “Flow Gates”. A flow gate is simply a collection of transmission lines that serve as a proxy for the calculation limits other than line thermal limits, such as voltage or transient stability limits. Grouping the network power lines into flowgates, reduces the amount of information that must be monitored when performing economic or operational security studies of the system.
This approach is often combined with contouring, to enhance the ability of the display to reveal at a glance the percentage power flow distributions (Power Transfer Distribution Factors PTDFs), in the network. In this way, studies and simulations can be performed to indicate possible network component shortcomings, before operations are performed on the real system.

Of the methods outlined in this paper, 3D interactive visualization is the most comprehensive and the most sophisticated, as it incorporates elements of the previous methods.
The need for this approach is supported by the fact that data of interest could include a long list of dependant and independent variables, such as bus voltage magnitudes, transmission line loadings, generator real and reactive power reserves, transformer tap and phase positions, scheduled and actual flows between areas and interface loadings.

With more advanced applications such as Optimal Power Flow (OPF), contingency analysis and Available Transmission Capacity (ATC) calculations, the above list gets even longer.

3D visualisation with interactivity is a network representation format that is developed with the following in mind.
There is no actual physical representation of system variables. Physical depictions are chosen as per the task at hand and the complexity and variety of the variables required to be displayed.
Secondly the environment must be highly interactive. This means, that if a controller clicks on a circuit breaker, with a mouse, a power flow solution takes place and the network is shown in its new state.
Thirdly, the hardware and software must be PC platform based, being the most common, with a view to expand to more sophisticated options such as 3D mice, shutter glasses for stereo-vision and head mounted displays.
Examples are shown, where starting from an old style single-line diagram the sense of depth is introduced using a perspective projection display, with generator capacities shown as cylinders on the z axis.

A further adaptation, is the use of shading to indicate generator reserves and contouring to show simultaneous depiction of system voltages and transmission line power loading.
The great advantage of 3D is its ability to show the relationship between variables, like the location and magnitude of any low system voltages, the current reactive power output and also the reactive reserves of the generators and capacitors in the system.
Such a situation is illustrated where the height of each generator cylinder is proportional to the current reactive power output, while the lighter top portion represents the reactive power reserves. The bus voltage values are indicated using a contour with only voltage values below 0.98 shaded. In another diagram current and reserve ATC is shown, with contouring used to indicate generator reserves. In another display the PTDF and heavily loaded lines are highlighted. Market participants would use this information, to identify grid congestions due to price driven power flow shunting.

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.

**2.14**
The current state of the art of the “Visualization of Power Systems” [17] is presented in a Final Report generated by the Power Engineering Research Centre, in 2002, of the same title, compiled by T J Overbye.

This report, like those before it, stresses the need to present vast amounts of data in a way that it can be assessed in an intuitive and quick manner. 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.

The original goals of this project were:

1) The development and use of 2D displays.
2) The development and use of 3D displays.
3) The performance of experiments to test the above with human controllers.

In addition, as the project progressed and several of these techniques were implemented (at Exelon and TVA) the results of these implementations are reported as well.
The report also states that there is an ongoing need to further develop and test visualization techniques with human controller's needs in mind.

**2D Techniques [17].**

All network controllers easily understand 2D visualization, as it has been around for a long time. It is quickly handled by computers in terms of processing and display.
Traditionally it has taken the form of either tables or one-line diagrams of power networks.
The only dynamic data on such displays have been numbers, coloured lights, to indicate the status of various devices and alarms. The following techniques have been developed to supplement or replace the existing displays, such as one-line animation and dynamically sized components.
Using this technique, small arrows are superimposed on the one-line display of a power line or transformer to indicate real power flow (MW). The size of the arrows is proportional to the value of the power. The effect becomes more dramatic when the flows are animated by showing the arrows to move at rates of greater than ten times per second. This makes the lines come to life. Pan and zoom functions allow for easy study of the network.
This approach works well for small systems. For larger ones only certain voltage levels should be displayed or specific sections zoomed into to avoid clutter.

The use of this approach to display reactive power is slightly more complex, since the reactive power value entering and leaving a line need not be the same. The line itself can even generate reactive power. All of that can be accommodated by suitable use of arrows that point in the right direction and having magnitudes proportional to the reactive power flows. This could result in arrows emerging from the middle of

lines etc. The simultaneous display of real and reactive power (which is relatively of a lesser value) can be done simultaneously and was found to be very useful for education purposes.

Another 2D technique is the use of pie charts to indicate the percentage loading of a line. The percentage fill of the pie represents percentage load and the size and colour of the pie can be dynamically sized to indicate that the loading has risen above a predetermined line threshold. This results in a display where only the critically loaded lines are highlighted, thus avoiding clutter.
It is important to adjust the size of the enlarged pie charts as the zoom function is used, to avoid covering up parts of the network.

Pie charts are useful up to the point where a large amount of data need to be displayed simultaneously. In such cases, the use of colour contouring overlaid on geographically depicted single line network diagrams is very useful.
If voltages are to be displayed by contours virtual values are generated, so as to make for continuous contours between busses. In this way, an overall view of the voltage profile for a whole region can be achieved. Initially blue was used for low and red for higher voltage values as mentioned in the previous paper. Further, it may be preferable to only use the contouring technique for voltage levels outside pre-determined limits such as 0.95% and 105% of nominal to make the displays "cleaner".
Contouring is also used for displaying other network values, such as electricity spot market prices denoted as the Locational Marginal Price (LMP) at a bus. Because of the continuous nature of colour contouring this type of display method does not show exact values of network quantities. To overcome this limitation a "hint" function is incorporated in order to identify exact values at specific points so as to allow detailed scrutiny when required. Instead of continuous contouring discreet contouring can be used. However, there is again loss of detail of values that fall within the range that a particular colour represents. The "hint" function is used in this instance as well.

It is also shown that colour contouring of different system parameters can be done simultaneously. For instance pie charts can be used to indicate line loading (out of spec lines only) together with colour contours of voltages at busses and a lighter colour contour of LMPs in the network. Line or transformer loadings can also be displayed by contours etc. The display of line Power Transfer Distribution Factors (PTDF) is another good application for contouring. Thus showing that a line with a 10% PTDF will carry 10% of a particular load transferred from a source to a load. Again, at a glance, the line loadings for a particular transaction can be assessed and optimised by control room staff.

The use of colour contouring is used for tabular displays as well, so that the actual numerical data is supplemented with cell background colour. Such a display allows the user to spot trends and important data much faster. The limitation of this

approach however is that only a small amount of data can be shown on a computer screen.
As more and more data are displayed the screen gets overloaded to the point where individual colour pixels are required to represent values. The display then appears as bands of colour the significance of which depends on the nature of the information displayed.

**3D Techniques [17].**

3D interactive visualization, as an extension of 2D displays, has been devised so that even more complex situations can be depicted. This could include bus voltage magnitudes, line loadings, generator real and reactive power reserves, transformer tap, and phase positions, scheduled and actual flow between areas and interface loadings. Even more advanced applications such as optimal power flow, contingency analysis and available transmission capacity calculations can also be accommodated.
It is important to recognise up front that no physical representations exist for the variables listed above. This means that the icons / effects used are metaphors which are intuitively grasped by the controllers. The starting point for these 3D representations is the common one-line diagram of the system, as used in 2D displays. Secondly the 3D environment must be highly interactive, so that important information can be obtained, as required if not displayed or if lying in the background of the picture.
The third issue, is the matter of software and hardware to be used. In this respect the PC platform is used for obvious reasons. This environment can be further augmented by the use of 3D mice, shutter glasses to simulate stereoscopic vision and head mounted displays, as mentioned in previous papers.

For software an existing power system analysis platform was modified using OpenGL. OpenGL allows perspective / viewpoint transformations, hidden surface removal, lighting effects and stereoscopic viewing. An important feature was the ability to perform operations on the display such as opening a breaker and have the display modified to show the new network conditions following a power flow solution of the modified system. The available viewing position options are dependant on a camera that can move around the landscape of the display, change height; rotate about the top to bottom and the side-to-side axes. All these can be controlled by use of the keyboard and a standard PC mouse. The impression of depth is created by the use of lighting and hiding of items behind vertical structures, such as cylinders depicting generator available and utilised reserves. To make the 3D environment acceptable for network operations the rate of display refreshing is very important. For the purpose of this study a 1,5 GHz Pentium machine with hardware support for OpenGL and refresh rates of 30 times per second were used for a small thirty bus network. For networks with 1100 busses, 375 generators and 1000 transmission lines, refresh rates of about 4.5 frames per second were attained.

The impression created by these 3D displays is quite impressive and compelling as presented in the displays shown in the report.

3D displays were used in the following ways:

- **For voltage and reactive power visualization**; where the bus voltages are shown by means of contours on the x & y axes (actually slightly below it), line active power flows by means of arrows and pie charts.
- The **generator reactive power reserves** were also included as vertical cylinders that show dark for used and light portions for available reserve.

This type of display is good at presenting qualitative information at a glance. It does not however do a good job at showing quantitative information such as real numerical values of voltage reactive power usage and reserve etc. It is therefore recommended that the 3D display be used as a supplement to the conventional 2D one-line and tabular versions.
In a more practical sense however the qualitative 3D depictions are quite adequate since the network controllers already know the reactive limits of their generators and actual numbers can be displayed as long as they are moved around so that they remain legible as the viewing angle changes. Alternatively, to prevent clutter, a controller can get all the numerical information required by selecting a network component on display, or use the hint facility for actual contour values as mentioned earlier.

Another 3D example in the report is the display of Available Transfer Capability (ATC) and generation reserves. ATC measures the ability of an energy market participant to transact power with other market participants, given the limited capacity of the transmission system.
In this respect generation reserves are shown on the vertical axis as cylinders and the ATCs are shown in the form of contours.
Alternatively, if power distribution factors are contoured on the x & y plane import ATCs are represented as cylinders along the z-axis. Area A then, can readily identify sources from which it can purchase energy, without being subjected to line loading restrictions that arise from PTDF limit values.

**EMS (Energy Management Centre) Implementation [17].**

In addition to the development of the visualization techniques described above, this report [17] contains information about the implementation of some of these techniques in the EMS control centres of two utilities which are Power Systems Engineering Research Center members, ComEd and TVA. The bulk of the development and implementation effort was provided by a third PERSC member, Power World Corporation. A number of CRT displays are shown in the report, of the

various 2D and 3D methods as implemented as well as an overview of the control room of one of the members mentioned.

Overall, the controllers 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”. 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, as it identifies the method used to solicit information from the controllers.
It is clearly stated that the approach used was not formal as 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. Below is a summary of the controller’s contributions in the form of suggestions and observations.

They are as follows:

- **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 users 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.

The final part of the report comprises of a summary of the findings of four experiments conducted, one per semester, with university Power Engineering students.

The first two experiments focused on the use of colour contours to display bus-voltage magnitude information.
The first of the two, used a 30-bus system on which contingencies were applied.

The Power Engineering students had to do two things:

- Acknowledge low voltage violations.
- Switch in one or more capacitors to correct the violation.

Preference was to be given to the closest capacitor for the lowest voltage bus identified.
The students were split into three groups each group having a different view of the network. These were:

- a group with tabular information of the network,
- a group with a one-line diagram and numerical values of the network parameters,
- a one-line diagram with added contour views of the network parameters.

The participants of the tabular group had quicker low voltage acknowledgement times than the one-line and the contour groups. However the one-line and contour groups scored equally fast in resolving the violations, both being faster than the tabular group.

The second experiment was designed to address the issue of three visualization options as applied to a more complex network of 118 busses. In this network, there were thirteen switched capacitors to be used in order to correct a sequence of thirty contingencies that would cause low voltages if left unattended.

The display options this time were:

- A one-line diagram with numbers showing the per unit voltages.
- A one-line diagram with colour contours showing only the per unit voltages.
- A one-line diagram showing both numbers and contours for the per unit voltages.

Statistical analysis of the results, that took into consideration the different load flow solution times, showed that there was not much difference across display conditions

for contingencies of low complexity. However, acknowledgement times consistently increased for the “numbers only” group, increased only slightly for the “numbers plus contour” group, and did not increase at all for the “contours only” group. Further, as far as acknowledgement of contingencies was concerned there was no trade-off between speed and accuracy for the “contour only” group, which is very significant. This remained consistent irrespective of contingency complexity.
In the second task of the experiment, were the participants had to resolve the contingencies, the “numbers only” group was significantly faster than the other two groups. The other two groups showed very little difference in their response times.
Since actual numbers were not required to resolve the contingencies, it seems that clutter may have played a big role in delaying the response times of the other two groups. Also slightly increased refresh times (0.35 sec vs. 0.1sec) for the two contour groups may have played a role.

From these findings, it seems that the contours are useful for identifying violations. From there, a switch to the simple one-line diagrams with numbers only would result in faster contingency resolution times. An alternative option would be to incorporate dimming features for the contours.

The last two experiments focused on the impact of animation on displays.
In the third experiment, the participants were presented with line violations, which they had to correct by adjusting the output of the generators in the network.

The display groups were of a one-line diagram with:

- Numbers only, using pie charts that changed colour and increased in size with overloads.
- Stationary arrows.
- Animated arrows.

On complex trials, the “numbers” group was faster in acknowledgement of line violations, whereas the “moving arrows” group was fastest in resolving the contingencies.
The “stationary arrows” group was in between the other two for both acknowledgement and resolution.

The last experiment, investigated the impact of animation on the display of Power Transfer Distribution Factors (PTDFs). These are calculated for “flow gates” or interfaces between system sectors or regions. Grouping network branches into flow gates reduces the amount of information that must be monitored when doing system analysis. A common flow gate is the sum of the tie lines between two areas.
In this experiment the participants were presented with a transaction indicated by arrows between areas. What they had to do was to first identify who was the buyer

and who was the seller, and then they had to select the optimum route for the power to flow through, to complete the transaction.

There were three groups, once more, each with a one-line diagram showing PTDF values with:

- Arrows that did not move.
- Arrows that moved uniformly.
- Arrows that moved proportionately to the PTDF values.

Here, animation was found to have a marked positive effect in reducing the time to identify the buyer and the seller pair with the highest accuracy. The plain motion group also did better than the stationary arrow group. The same results were achieved as in the part of the experiment were the optimum route was selected. However uniform motion results were very close to the proportional motion results.
It was concluded that more research was necessary to clearly explore the last two option characteristics.

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.

**2.15**
A comprehensive listing of Power System components, factors, and interactions is presented in a report commissioned by EPRI entitled "Interconnected Power Dynamics Tutorial" [18]. This represents the theoretical basis of Power System operation.

**2.16**
In a further paper titled "Human Factors Aspects of Power System Visualizations" [19] T J Overbye presents the results of the evaluations carried out on the various Power system visualization methods employed in the PSERC report mentioned above. This has been already reviewed under the report review.

## 3. OVERALL COMMENTS AND OBSERVATIONS FROM THE POWER SYSTEM VISUALIZATION REVIEW.

It appears that the prevailing view is that controllers are not considered as an integral part of a transmission network. 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, **controllers are still considered to stand apart from** such **a network in order to "control" it.** 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" of said controllers, however **it is still not known what**

**controllers do with information inside their heads.** It is important to note, that interfaces are been designed by individuals that do not appear to be controllers themselves. These interfaces are then tested on non-experts (students are often used to determine the usefulness of new MMIs). In cases where the computer displays have been tested by expert controllers the internal representations of these experts are not noted. This means that if other experts have different preferences the displays will not meet their requirements.

**The excerpts below are a compilation of all that is mentioned, in the papers reviewed in this section, about the mental representations of Grid Controllers.**

Bainbridge [3] points out that information is processed in controllers' minds. This may sound obvious, but as will be seen **internal processing strategies and visualizations of expert network controllers are entirely absent in the literature reviewed thus far.**

In the EPRI report of 1982 [6] it is acknowledged that controllers' mental processes must not be disrupted by the time that it takes for computers to process and respond to information. In the same paper controller aptitudes and training objectives are mentioned as areas of consideration.

**Hokey [7] acknowledges the cognitive demands made on controllers as well as the resulting stress that arises from their work.**

**Peter Knothe [8] states:** "Insight into the nature and behavioural 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**." However the rest of the paper deals with external factors and not the controllers themselves. He does say however that help should be sought from the human engineering field.

Mahadev [9] mentions the term " **natural cogniti ve abilities** " he also states that controllers go through mental steps in order to interpret data or information as the case may be. However no such strategies are identified or shown. Further it is stated that automatic control systems, human controllers, and design engineers have different data and / or information needs. From this he concludes that, for controllers in particular, "the purpose of computing is insight not numbers (Hamming [9 -[1]])." The internal representations of insight however are not identified.
It is particularly emphasised that human controllers have difficulty in using numerical data representations because conscious processing normally can take place with a maximum of 7 +/- 2 bits of information (G Miller 1956 [55-p267]) thus making large numerical data sets difficult to use.
**The rest of the paper is about external factors pertaining to MMIs.**

The paper concludes by stating that the proposed representation methodology will be presented to network controllers so that they can offer comments as to its suitability in meeting their needs.

Mitsui [11] states that the colours used for computer displays must be carefully chosen so that they meet the needs and expectations of end users. 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 (unconscious information processing).** 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.

**Mahadev [12] mentions the "at a glance" (this can imply unconscious processing) concept of obtaining information and the case is made for the summation of data in graphic form using 2D and 3D displays.**
He goes on [13] to discuss the Task Adaptive Visualization (TAV) approach. This approach is centred on the concept of "Show me what I need to see" and therefore some form of decision-making by the computer tool is assumed. Further in the paper, it is stated that the Full Graphics User Interface (FGUI) has not improved maters in the control room, as it requires effort to manipulate windows etc. This is not an improvement in overall efficiency compared to the traditional Character Graphics User Interface (CGUI).

**None of the other papers mention the internal representations, visualizations or mental models and strategies that controllers use.**

## 4. REVIEW OF THE INDUSTRIAL PSYCHOLOGY FIELD: WITH EMPHASIS ON VERBAL PROTOCOL ANALYSIS (VPA) [20-45].

In the abstract of his masters dissertation [20] A Thatcher (1995) 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."
He goes on to identify a number of data gathering and data analysing techniques that can be used to determine aspects of those inner workings as well as the role of the human controller in a complex control environment.
The method he used to do his project was selected after evaluating and comparing a variety of options that are listed in the dissertation. The method consists of the following parts:

- Semi-structured interviews were conducted to identify some of the tasks that the controllers perform.
- From the above findings tasks were designed on a process simulator and were then given to the controllers to execute.
- Their performance was video recorded and verbal protocols were obtained.
- All the data was analysed to investigate the controllers' problem solving and information gathering strategies.

Once all the above were done the results obtained were analysed by the use of **three techniques**. They were **behavioural flow charts**, explicit analysis of the **verbal protocol** content and **multi dimensional scaling (MDS)**.
He quotes Robson and Crellin [20] (1989) "Verbal protocol analysis allows researchers to obtain a diverse amount of rich data about cognitive process while performing complex process control tasks including data on problem solving, fault diagnosis, **mental models,** and diagnostic judgment.

Among other things, Thatcher's work reveals that there were large qualitative differences in the controller's task execution strategies as well as in their information gathering approaches.
Further it is stated that the controllers involved do not hold consistent and stable mental models but rather update their mental representations on a moment-to-moment basis.
**He concludes by stating that these techniques show promise for the investigation of cognitive engineering problems.**

From these findings it seems that the emphasis of the study was on on-the-job performance, problem solving strategies and cognitive ergonomics, all underpinned by internal representations, which are not considered.

The Cognitive Task analysis methods considered by Thatcher before he chose the three mentioned above are:

**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 categorisation and has limited application to cognitive processing that results in human error.

**Cognitive Modelling.**
In this category the GOMS model by Card, Moran, and Newell (1980) and extended GOMS model of Arend [20] (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) [20].
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.**
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 modelling 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 Modelling.**
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, which they have to resolve.

**Cognitive Walk Through.**
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.**
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 investigated.
Again the emphasis is mainly on performance of tasks and not on the visualizations of the systems by the operators. There may be some merit in recording such eye movements and using the information as a platform to ask questions of the controllers.
Terms such as "visual momentum" and "cognitive lock up" are used to suggest that long eye fixations may represent problems with comprehension. However, given the great differences between individuals as well as other reasons for eye fixations this method does not have much value for his work.
It could however have merit in as far as the evaluation of control-room equipment layout is concerned. The method can be used as a complement to discourse analysis.

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

**Questionnaire Analysis.**
This involves “what and how” questions as well as drawing maps of task descriptions. This technique is “prescriptive” and therefore not suitable for the elicitation of metaphors and visualizations.

**Structured interviews.**
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 expressible is provided.
An improvement on this is verbal protocol analysis.

**Verbal Protocol Analysis (VPA).**
This is the most widely utilised 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 the latter 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.**

The following information comes directly from Thatcher’s dissertation.

Thatcher [20-p 14] (1995) points out that controllers’ mental models may be sketchy and incomplete. This may mean that more work should be done to reveal their mental models of the network so that decisions about computer display designs can be meaningful. “Visual Momentum” and its importance is discussed [20-p 15]. This means that the controllers’ cognitive requirements should be matched with the display system, its format, etc. The issue of trust in the machine as well as self-confidence is considered next [20-p 16]. He says that systems need to give accurate feedback to controllers about how the system is performing, particularly about automated functions, to help them make informed choices. He states that "a well calibrated operator is the most competent".

Cognitive functioning declines with age although over-learned tasks don’t decline due to experience. He continues to say that cognitive styles stabilize by eight years of age. 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

he concludes that systems need to be adaptable to the users preferences, abilities, and styles.

Since 1987 there has been a return to verbal protocol analysis as a more modern form of introspection [20-p 35]. Ericsson and Simon developed a comprehensive methodology of VPA in 1984 [20]. 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 [20-p 38].

VPA has also received sharp criticism particularly that of Nisbett and Wilson (1977) [20]. They conducted a series of experiments that showed that higher order cognitive processes and their reports were based on a-priori causal theories and judgements. The idea is that the correlation between what one thinks and what he says that he is thinking cannot be tested.
**There are three main arguments against VPA, they are:**

**The concurrent verbalisation argument** suggests that the process of concurrent verbalisation distorts the ongoing cognitive process, by either improving or deteriorating performance [20-p39].

**The cognitivist attack** 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 higher order processes are out of awareness.

**The epiphenomenality argument** 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.

However elaborate **counterarguments** [20-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 rationalising is possible.**
Finally it is concluded [20-p 46] that VPA can be used as preliminary level analysis and as a method to construct hypotheses about cognitive processes.

The use of VPA in complex systems were the protocols were videotaped have been shown to hold much promise [20-p 47-49]. Particularly for the elicitation of mental models Kieras and Bovair 1984 and Hegarty et al 1989 both employed VPA to look

specifically at user's (controller's) mental representations of systems [20-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 [20-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 modelling in the subjects as well as information on qualitative decision making.

The above findings, and value extracted from VPA results, are further corroborated in numerous examples given of studies by other researchers [20-p 51-59]. In these reports a number of substantial benefits 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.

Retrospective VPA was also found to be accurate and therefore very useful where video recording of actual performance of tasks was captured [20-p 57].
VPA was also compared to other data gathering techniques as listed earlier and found to be a superior tool for data gathering [20-p 58] particularly when live video capture was used.

**Rationale And Procedure [20-p 60].**

Thatcher continues by stipulating that it is necessary to work with a technique of cognitive task analysis that is applicable to the situation at hand. In his case it was the boiler control room of a coal-fired power station (Matimba). The process should also be tailored to meet the unique conditions that prevail in the environment at hand. He states that there are two main components to the method as first put forth by Drury (1983) [20-p 60]. They are:

- A formal task description in which semi-structured interviews with controllers and their supervisors are conducted in order to gain an understanding of the types of tasks that controllers perform and the knowledge that is required to perform them.

- The verbal protocol analysis itself.

It is particularly interesting that under the heading "rationale" Thatcher points out that the reason for embarking on his study was to shed light on that environment since, "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".

Further he states that “the designers of the 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”.

He goes on to describe the organisational structure and the number of staff involved together with who he interviewed, where, in whose presence etc. Twenty-two people were interviewed between 1-7 December 1993 [20-p 64].

The interview procedure was as follows:

- Begin with a short introduction and why the research was being conducted, what the focus of the study was. In his case the focus was the operating system.
- Ask, what are the common tasks performed with the OS-254 control system?
- Ask, what are the less common tasks performed with OS-254 control system?
- Ask, what was the most unusual task or emergency to be dealt with?
- A description of the VPA was offered.
- The interviewees were asked if they had any questions themselves.

He points out that probing questions were asked focusing on the details of the interviewees’ responses. The simulator instructors and shift supervisors were also asked the same questions as the operators [20-p 65]. The results were presented in table form [20-p 66]. A number of problems with the OS 254 control system were also identified and presented [20-p 68] as well as other information from the instructors and supervisors [20-p 69-72].

**Protocol Gathering and Analysis.**

Verbal protocols and behavioural data were collected while actual operators were involved in a routine task (this was selected after the interviews were carried out) on a high fidelity simulator.
The operators that agreed to participate (eight out of eighteen or 44.4%) are then described.
The simulator at Matimba is also described [20-p 73-75].
The process control task with diagrams of the boiler and auxiliary equipment is then described [20-p 76-78].

The procedure for the VPA of the eight subjects which was conducted, between 7$^{th}$ and 10$^{th}$ march 1994, is described as follows:

- The subjects were instructed as follows “In this experiment we are interested in what you say to yourself (this is based on a presumption that they all talk to themselves as they work, not necessarily true for all) as you perform some

tasks that we give you. In order to do this I am going to ask you to THINK ALOUD as you work on the tasks. What I mean by think aloud is that I want you to say out loud EVERYTHING that you say to yourself (again this is inadequate as they may be processing information in ways other than verbal) silently. Just act as if you are alone in a room speaking to yourself. If you are silent for any length of time I will remind you to keep thinking aloud." They could think aloud in the language of their preference.

- The initial conditions on the simulator were explained to the subject and he was asked if he had any questions.
- The procedure was then video recorded as this allows the maximum capture of information that that can be later scrutinised repeatedly for different aspects of the operators' performance.
- The subjects were prompted during long periods of silence and the simulator instructor was on hand to ensure that there were no problems with the simulator as well to provide additional information.
- The captured video material was then shown to the subjects for further comments and additional information or corrections. Some of the video footage was not useful as the cameras were not used properly.
- The verbalisations were transcribed verbatim for each subject.
- Rate of verbalisation was calculated for each subject as well the amount of time that each person took to complete the task.
- Information was obtained on the subtasks that an operator was performing and when each operator changed their subtasks. This information was complimented with information on where each operator was looking on the control panel. The simulator was divided into five distinct areas for analysis purposes. The time spent looking at each area was calculated.
- The results were of the protocol and behavioural pattern analysis were compiled and presented under the following headings:
    - Rate of verbalisation.
    - Time spent on primary task and time spent looking at each of the five areas on the simulator.
    - Amount of time spent looking in a certain direction and average time of it.
    - Correlations of average time of where a subject is looking with length of time on the primary task.

- These findings were analysed and commented upon [20-p 81-87].
- A statistical method of analysis was then applied, Multi Dimensional Scaling (MDS), to the previous results. **The findings of the statistical analysis however only highlighted the relationships and variation of the participants' observable behaviours [20-p 89-106].**
  It was concluded that the subjects used a wide variety of approaches to gather information and to perform particular tasks. The variation is evident in the spread of the subjects on each of the two dimensions of the analysis matrix.

In summary, the preliminary interviews provided the following information:

- A list of the large number of tasks that the operators are supposed to perform.
- A list of the more common tasks.
- How operators accessed information and what information was needed.
- Anecdotal information on unusual situations.
- Information about the wide variety of situation that can arise.
- Problems with the control system OS254.
- Information on the knowledge base and expertise that operators are given.

The VPA provided information about the annotation of the behavioural 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. The use of the video camera proved a very useful asset for information gathering.
A great deal of variation of how subjects perform tasks (i.e. strategies and subtask use) was identified, i.e. how information was sought and accessed in order to perform different tasks.

From the MDS analysis of the first 100 seconds (that was the time that the study considered) of the firing of the first oil burner (which is used to start up one of the boilers), a tentative interpretation of **two underlying dimensions** was **considered**.
They were the direction of a **subject's gaze** and the **performance of tasks and subtasks**. The analysis of these two dimensions revealed a large variation between individuals, even for the sort study time of 100 seconds.

The overall value of the study was that it was successful in generating hypotheses and questions for further investigation [20-p 108].

Under the heading "Discussion" it is noted that six subjects are quite adequate to provide reliable information as in a previous study using VPA [20-Nielsen,1994] found that six out of twenty four subjects were sufficient to provide 86% of the useful data. It is also noted that VPAs have been carried out with as little as three subjects with good results.
The rest of the section comments on behavioural and other explicit behaviour comparisons with previous studies. These do not have any bearing on the work that I propose to do.

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.." 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.

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 [20-p 109-119].

A number of **limitations** [20-p 120-125] are also listed:

- The interviewing process does not claim to cover the complete scope of the work of the subjects.
- The VPA is intended to generate more questions than it answers.
- The tasks selected may not be such as to be general to all such boiler plants.
- The subjects, due to time constraints, did not practice thinking aloud.
- There were no accurate records of data presented by the simulator.
- Not all eye movements were captured due to technical limitations.
- It is not clear if operators fixated their attention on different areas on the simulator due to processing or just thinking of other things.
- Remote microphones were not available to use.
- **Only the explicit analysis of the verbal protocols was done.**
- **A deeper implicit analysis was <u>not done</u>.**
- The various subjects used the simulator with or without the OS 254 option.
- The 100 sec MDS analysis of operator performance may have been too short, yet it supported the VPA findings.
- The findings can not be generalised to other such environments due to the uniqueness of the situation, the people involved, the equipment used etc.
- The time consuming nature of the data analysis and categorisation, even for the shortest protocols.

Under **suggestions for improvement** the following are listed [20-p 125-126].

- Studies using different operators.
- Variation of the test conditions (problem and crisis conditions).
- Increase of the thinking aloud time.
- Use of better recording equipment (lapel microphones, more than one camera).
- Include printouts of the simulator alarms and other visual data in the analysis.
- Further analysis and investigation, of the implicit information about subjects' mental models.
- Increase of the time window of the MDS analysis.

The **benefits and applications of the cognitive task analysis** are [20-p 127-130] that it could be used to:

- Evaluate the design of control rooms and control panels.

- Help designers to appreciate the importance of asking the right questions, before attempting to design a control panel or a data representation system.
- Create better understanding of operator needs, cognitive resources, and processes.
- Help designers learn to work within the constraints of human information processing.
- Design and implement training regimes.
- Understand what information operators need and how they need it presented.
- Understand how they process it and how they decide on control strategies and actions.
- Facilitate the eventual emergence of a comprehensive mental model.
- Provide operators with adequate metaphors such that would optimise their performance.
- Further pure cognitive research on specific design questions.
- Test design solutions.

## 5. OVERALL COMMENTS STEMMING FROM THATCHER'S DISSERTATION.

It should be noted that in the papers reviewed by Thatcher (included in his references list) there is no explicit mention of the visual representations of the mental experience of subjects. The visual, auditory, and kinaesthetic sub-modality structures are not mentioned at all. In some cases there are mental models mentioned from which it could be construed that such visual representations could be accommodated. However, no mention is made explicitly.

It is important to draw the distinction between Thatcher's emphasis on problem solving strategy investigation and the emphasis of this research, which is to go a step further, into the identification of the mental models and metaphors that underpin the above strategies and problem solving efforts.
Of the various elicitation methods mentioned by Thatcher, behavioural flow charts and verbal protocol analysis were used in this research as well. MDS was not used as it does not pertain to internal mental model elicitation. The findings of the MDS statistical analysis do not delve into the mental models of the operators. They only highlight the relationships and variation of the observable behaviours of subjects.

The VPA methodology was complemented by the use of the "Metamodel" approach of J Grinder [46] in order to expand and uncover the underlying mental complex equivalences that the controllers use to give meaning to their tasks. In the case of this work the verbal protocol methodology was extended to include subjects' descriptions (not explanations or reasoning) of various aspects of their mental experience i.e. whether it is visual, auditory, kinaesthetic, olfactory, gustatory etc.

## 6. REVIEW OF THE COGNITIVE PSYCHOLOGY AND EMOTIONS THEORY FIELDS [60-63].

Having concluded the VPA review, an accepted theory of cognitive psychology was sought in order to establish the underlying structure of the mental processes that I was looking for.
To accomplish this, three sources were investigated. The first was the book "How the Mind Works" [60] by Massachusetts Institute of Technology Professor of Psychology S Pinker; the second was the standard textbook of cognitive psychology "Cognitive Psychology and its Implications" [61] by Carnegie Melon Professor of Cognitive Science J R Anderson; and the third was the work of Dr I Shalif "Focussing on the Emotions of Daily Life, a Guide for their Maintenance" [62].

What follows is a collection of excerpts from these books, shown in the order in which that appear in the books. The purpose of this collection of statements is to show that it is well established that the human mind has layers, some conscious and others not so conscious, and that the other than conscious layers support the operation of the conscious ones. It is the organization of these other than conscious layers that determine expertise, in which case the methods used in this research will be such as to unveil these layers and in so doing show the elements of "expertise".
The fact that the excerpts below have been selected for the purpose of this research creates a problem with the flow of the reviews, as the authors have written their books in their own particular order. It is important therefore to keep in mind, that the statements presented below are simply there to show that this research is based on accepted cognitive theory, of which the excerpts are but samples. At the end of each book review is a section of overall points that capture the main ideas as they pertain to this research.

## 7. REVIEW OF "HOW THE MIND WORKS" BY S PINKER[60].

In his book "How the Mind Works" Pinker presents information very similar to that of Anderson, 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 fleshed this idea out by noting that intelligence consists of specifying a goal, assessing the current situation to see how it differs from the goal, and applying a set of operations that reduce the difference. We have desires, and we pursue them using beliefs, which when all goes well, are at least approximately or probabilistically true.

The old theory of stimulus and response has been proven wrong. **We act because we believe things are in a certain way and we want them to be in another**." [60-p 62].
The term "beliefs" could be replaced by the term "mental models".

**"The computational theory of the mind has quietly entrenched itself in neuroscience**, the study of the physiology of the brain and nervous system. No corner of the field is untouched by the idea that information processing is the fundamental activity of the brain. And as we shall see the tree of dendrites (input fibbers) on each neuron appears to perform the basic logical and statistical operations underlying computation. Information-theoretic terms such as "signals", "codes", "representations", "transformations", and "processing" suffuse the language of neuroscience [60-p 83].

"The blossoming came from a central agenda for psychology set by the computational theory: discovering the form of mental representations (the symbol inscriptions used by the mind) and the processes (the "demons") that access them. Like Plato's analogy of the cave. The information in an internal representation is all that we CAN know about the world." [60-p 84]

"Pinning down mental representations is the route to rigor in psychology.
**The way people generalize is perhaps the most telltale sign that the mind uses mental representations, and lots of them."** [60-p 85]
By giving various examples the author shows how we can know that our mind contains mental representations specific to abstract entries for words, not just the shapes of the words when they are printed [60-p 86].
The various mental representations connected with a concept like elk can be shown in a single diagram, sometimes called a semantic network, knowledge representation, or propositional database.

Fig. A2 below, is but a fragment of the immense multimedia dictionary, encyclopaedia, and how-to manual we keep in our heads. **We find these layers upon layers of representations everywhere we look in the mind.** Equally we have representations for motor trajectories that in turn engage muscle contractions and limb movements that accomplish them. The trajectory would be translated into actual motions by lower level control programs for each appendage. In the case of "Sally" (a person fleeing form a fire) the case is made for her being modular, as one part of her assesses danger, another decides whether to flee, yet another figures out how to flee [60-p 87].

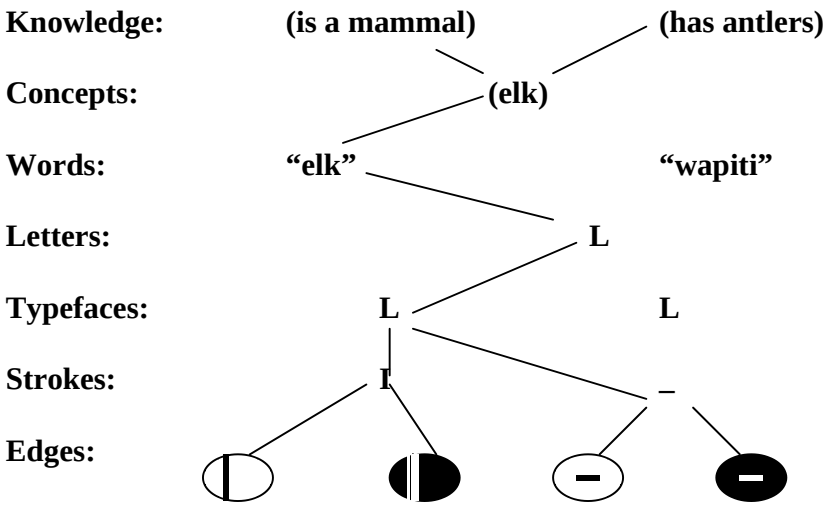



**Fig. A2.** Semantic Network for the word Elk.

Laboratory tests have revealed that the human brain uses at least **four major formats of representation.**
**One** format is **the visual image**, which is like a template in a two dimensional picture-like mosaic.
**Two**, 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 (part of short term memory, i.e. repeating a tel. 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) [60-p 89].

A **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 we capture the gist of a book and 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** [60-p 90].
**The modular multi-format minds that we have:**

- **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** [60-p 91].

Modular design is a characteristic of all complex systems. Like bodies (organs), armies (divisions), books (chapters) etc. [60-p 92].

Pinker mentions two refutations of the computational model of the mind. They are:

- John Searle's refutation, which states that it does not include understanding in the manipulation of data. He says that it lacks intentionality, the connection between a symbol and what it means [60-p 94].
  Pinker refutes Searle's view by saying that the word "understand" remains undefined therefore there is no argument [60-p 95 & 96].

- R. Penrose's refutation, which states that the theory does not account for the ability to perceive that which cannot come from computation. He looks to quantum effects for the answer to the question of consciousness [60-p 97]. Pinker refutes by saying that Penrose's theory has not been well received by other scientists and therefore does not stand on solid ground [60-p 98].

The book then continues with further information.
In the mind fuzzy and crisp versions of the same category can live side by side [60-p 127].

**Consciousness is subdivided into:**

**Self –knowledge**.
This comes down to memory and perception and is no mystery at all [60-p 134].

**Access to information**.
This refers to information about conscious processes like thoughts, and unconscious processes like the conversion of 2D into 3D images, from the retina to depth perception. This is like any computer, therefore again it is not a mystery [60-p 135].

Sentience.
Raw "feels" or subjective experience. This remains the ultimate mystery.

Attention is likened to a spotlight so that there is conscious serial attention however this can go on together with unconscious parallel processing [60-p 140].
Unconscious absentminded looking at letters may result in reading the wrong word by rearrangement [60-p 142].

We remember common and recent events.
**We register events as having an emotional signature** [60-p 143].

The sense of "I" is under assault as the mind is a society 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 [60-p 144].
This statement is of particular significance to the research that I conducted.

Sentience remains a mystery but does not impede our understanding of how the mind works [60-p 147].

**The mind works as a collection of expert modules** [60-p 255].

The emphasis on seeing our mental representations over what is out there can be deduced from the fact that only artists seem to see the world as it appears, we see our versions of the objects in it [60-p 258].
**J Gibson argues that we have either a "visual field" (retinal frame) or a "visual world" (world-aligned frame) way of perceiving and we can switch between them** [60-p 264].
**Imagination, particularly in visual form, is an alternative mode of mental processing that is far more useful in dealing with maters of the world out there.** 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 [60-p 285].

Space in the world is represented as space in the brain neural connections [60-p 287].

It has been shown that holding a mental image interferes with faint and fine visual details (the Perky effect). The visual motor coordination also suffers. When people see some shapes and imagine others later they sometimes have trouble remembering which was which [60-p 288].
The vivid mental images cause more activation of the visual cortex than the real ones. This runs the risk of confusing imagination with reality [60, D Symons- p 289].

**The mind operates either in terms / concepts that are related or in pictures that capture the whole** [60-p 290].I**t can zoom, shrink, pan, scan, trace colour etc**. [60-p 292].

Chess masters remember meaningful relations between pieces not just their spatial arrangement, they are not good at all at that [60-p 295].

Fuzzy categorization works by recording the clusters in reality, predicting by similarity and correlation.
Well-defined categories work by identifying the laws that put the clusters there, their predictive power comes from deduction. Real science is famous for transcending fuzzy feelings of similarity and getting at underling laws [60-p 309].

**When asked questions that get processed by theorizing, people come up with absurd ideas when the same questions are processed visually the right answers seem obvious** [60-p 320].

Space and force pervade language so that a handful of concepts about places, paths, motions, agency, and causation underlie the literal or figurative meanings of tens of thousands of words and constructions in all languages. They appear to be the vocabulary and syntax of mentalese, the language of thought [60-p 355].
This handful of concepts that capture the key features of encounters among objects and forces can be used to deal with abstruse domains by removing the original content (from the human conditions of fighting, food, health etc.) and substituting it with new symbols [60-p 358].
Because human thoughts are combinatorial (simple parts combine), and recursive (parts can be embedded within parts), breathtaking expanses of knowledge can be explored with a finite inventory of mental tools [60-p 360].

Geniuses are at it all the time they spend over 10 years paying their dues. Then they refine and tweak their attempts until a break through. They also leave lots of bad attempts. They are not freaks they are like us, which is what our combinatorial adapted minds are for [60-p 361].

**The "amok" state is triggered by an idea!** [60-p 364]
Emotions like happiness, sadness, anger, fear, disgust, and surprise are recognised by everyone everywhere. Emotions are innate to all humans (blind and deaf people have the same emotions) [60-p 366].
Cultures differ in how they express emotions in public [60-p 369].
The triune brain (functionally the brain is considered as having three parts) works in tandem, not one part over the other. The emotions can be reprogrammed by selection, they focus mental activity [60-p 371].
**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 [60-p 373]. **The main calming agents 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. When we are unhappy we work for the things that make us happy when we are happy we keep the status quo [60-p 389].
People are happy when they feel better off than their neighbours, unhappy when they feel worse off. The amount of violence in a society is more closely related to its inequality than to its poverty. The second tragedy of happiness is that people adapt to their circumstances good or bad. From that neutral point improvement is happiness, and loss is misery. From surveys conducted in the industrialized world, 80% of those poled were fairly satisfied and 30% were very happy. Overall however, industrialization has not resulted in people being happier with more "stuff". There are twice as many negative emotions as there are positive and losses are more keenly

felt than gains [60-p 391/2]. **It is not the rich, privileged, robust, or good looking who are happy, it is those who have spouses, friends, religion, and challenging meaningful work. The direct pursuit of happiness is a recipe for an unhappy life** [60-p 392/3]. **Our most ardent emotions are evoked by people** [60-p 396]. We have evolved keen emotion detectors.

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 [60-p 424].
Personalities differ in at least five major ways:

- Sociable or retiring (extrovert / introvert)
- Worrying or calm and self satisfied (neurotic / stable)
- Courteous and trusting or rude and suspicious (agreeable / antagonistic)
- Careful or careless (conscientious / undirected)
- Daring or conforming (open / not-open)

50% of the personality is genetic. Most of the other 50% is acquired from interaction with a peer group not the parents; they play their role at conception! [60-p 448/9]
Firstborns are less open (more conforming, traditional, and closely identified with parents), more conscientious (more responsible, achievement oriented, serious and organized), more antagonistic (less agreeable, approachable, popular, and easy going), and more neurotic (less well-adjusted, more anxious). They are more extroverted (more “leaderly” and assertive), though the evidence is cloudy because they are more serious which makes them seem more introverted. Personality is an adaptation [60-p 454].

Real people face dilemmas of cooperation again and again and can remember past treacheries or good turns and play accordingly. The tit-for-tat strategy of cooperative on the first move and then do what your partner did on the move before beat sixty two other strategies [60-p 504)]. The strategy of sharing high-variance foods and hoarding low-variance foods (or recourses) has evolved over millennia in human groups. This is a survival strategy by which scarce resources are banked as it were, with other members of the foraging group, in the process of sharing [60-p 505].

**The mind is a neural computer, fitted by natural selection with combinatorial algorithms for causal and probabilistic reasoning about plants, animals, objects, and people. It is driven by goal states that served biological fitness in ancestral environments such as food, sex, safety, parenthood, friendship, status, and knowledge. The toolbox however can be used to assemble Sunday afternoon projects of dubious adaptive value** [60-p 524].

We push the pleasure button with vivid artificial colours and patterns [60-p 528].
Music communicates nothing but formless emotion [60-p 529].

Humour begins with a train of thought in one frame of reference that bumps up against an anomaly: an event or statement that makes no sense in the context that has come before. The anomaly can be solved by shifting to a different frame of reference, one in which the event does make sense. And within that frame someone's dignity has been downgraded [60-p 549].
The mind is not able to comprehend all mysteries, it is limited to the realm of its evolution, the problems of the natural world and by extension to other problems that make use of its toolbox by substitution [60-p 563].

The core of meaning, the simple act of referring to something, remains a puzzle because it stands strangely apart from any causal connection between the thing referred to and the person referring. Our thoroughgoing perplexity about the enigmas of consciousness, self, will, and knowledge may come from a mismatch between the very nature of these problems and the computational apparatus that natural selection has fitted us with.
**The most undeniable thing there is, our own awareness, would be forever beyond our conceptual grasp**. Our bafflement at the mysteries of the ages may have been the price we paid for a combinatorial mind that opened up a world of words and sentences, of theories and equations, poems and melodies, of jokes and stories, the very things that make a mind worth having [60-p 565].

## 8. OVERALL COMMENTS FROM THE REVIEW OF "HOW THE MIND WORKS".

For the purpose of this research the following comments establish a structure of the mind, in the words of Stephen Pinker, as follows.

Intelligence consists of specifying a goal, assessing the current situation to see how it differs from the goal, and applying a set of operations that reduce the difference. We have desires, and we pursue them using beliefs (or mental models), which when all goes well, are at least approximately or probabilistically true.
This opening statement captures the essence of the work that the NCC controllers do.

The way people generalize is perhaps the most telltale sign that the mind uses mental representations, and lots of them.
We find these layers upon layers of representations everywhere we look in the mind.
Mind has four major formats of representation:

- The visual image;
- The grammatical representation;
- Phonological representation; and
- "Mentalese".

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. The modular multi-format minds that we have:

- 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.

Modular design is a characteristic of all complex systems.

The mind works as a collection of expert modules
J Gibson argues that we have either a “visual field” (retinal frame) or a “visual world” (world-aligned frame) way of perceiving and we can switch between them. The mind operates either in terms / concepts that are related or in pictures that capture the whole. It can zoom, shrink, pan, scan, trace colour etc.
Visual representation of problems leads to more accurate solutions than the process of theorizing. Because human thoughts are combinatorial (simple parts combine), and recursive (parts can be embedded within parts), breathtaking expanses of knowledge can be explored with a finite inventory of mental tools.

Emotions are of particular importance. Attention is likened to a spotlight so that there is conscious serial attention, however this can go on together with unconscious parallel processing. We register events as having an emotional signature.
The sense of "I" is under assault as the mind is a society 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.
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. The main calming agents are: predictability, allies within shouting distance, and a sense of competence and control.
When we are unhappy we work for the things that make us happy when we are happy we keep the status quo.

The mind is a neural computer, fitted by natural selection with combinatorial algorithms for causal and probabilistic reasoning about plants, animals, objects, and people. It is driven by goal states that served biological fitness in ancestral environments such as food, sex, safety, parenthood, friendship, status, and knowledge. The toolbox however can be used to assemble Sunday afternoon projects of dubious adaptive value.

## 9. REVIEW OF "COGNITIVE PSYCHOLOGY AND ITS IMPLICATIONS" BY J. R. ANDERSON [61].

The next item to be reviewed is the standard textbook on cognitive psychology "Cognitive Psychology and its Implications" by Anderson.

In this textbook it is stated that cognitive psychology began between 1950 and 1970 [61-p 10] and that it draws on information theory, artificial intelligence and linguistics. Information processing is the dominant approach in C P. This is illustrated by experiments that show increase 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 [61-p 32].**
In performing its function the brain works in such a way as to first extract shapes from a visual scene and then recognizing the items extracted.
An object therefore is a gestalt [61-p 44] of various segments of perceived information.
Incoming information (particularly visual) can be recognized by template matching (not very credible method); feature analysis (recognizing features then combining them in a whole); object recognition (identifying geons [61-p 52] or sub objects and putting them together). Similar processes are utilized for speech recognition.
Objects are further considered in terms of the context in which they appear.

The following sequence illustrates what happens with such a model of perception [61-p 73].

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

**Fig. A3.** Model of Perception, sequence of events.

Incoming information is further filtered, attenuated, or focussed on with or without eye movements. Visual information can be retained in a sensory memory briefly, where it is attended to [61-p 87]. Where elements of incoming information are similar, distinctions take longer to make. The opposite half of the brain processes information presented in a particular half of the visual field.

The practice of tasks allows for less conscious processing.
**It is particularly important to note "… that processes can become automatic with enough practice. When they do, devoting attention to them is no longer necessary and performance is no longer affected by the number of processes being performed simultaneously".** Subjects find it easier to recognise patterns or objects, which they expect [61-p 97] to appear. In the case of words the process is so automatic that it is very difficult not to read them automatically [61-p 100].

People can divide their attention and their efforts in varying proportions to attend to multiple tasks. When a person 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" do not conflict during parallel processing [61-p 104].
**The brain is a complex parallel processing device.**

The amount of time required to perform rotation of mental images is directly linked to the extent to which they are rotated [61-p 113]. The closer items are to one another the quicker they can be scanned. In scanning a visual image there will be interference if simultaneous spatial processing of other information is required. There is evidence that different areas of the brain are responsible for spatial and visual aspects of information [61-p 120]. Visual images are not as easy to interpret as actual pictures of objects [61-p 122]. Objects that share similar features are more difficult to distinguish.
**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 organisation of parts within parts [61-p 125].**

Often the broader concept in a hierarchy is used to determine the relative value of sub parts within it. The beginning and end portions of serial information are more significant in processing the information [61-p 130]. The further two items are on a linear sequence the easier it is to distinguish them. The meaning of information is retained instead of the actual wording that it was presented in, the same is true of pictures. **As information is given meaning it is easier to retain [61-p 139].**

Schemas represent categorical knowledge according to a slot structure (materials: wood etc, shape: rectilinear etc. for house). Scripts are schemas used for events [61-p 164]. 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 [61-p 183]. **Memories are stored in networks of associations.** However the results of memory practice taper off according to a power rule. Elaborate processing of information (making use of multiple modalities) will result in better memory retention more so than just the intention to learn [61-p 191]. Question generation and answering lead to better memory for text material [61-p 196]. Concepts that have been simplified can be retrieved much quicker. Information that has been learned in

a particular context can be interfered with by information from outside the original context.

Often what is plausible is presented as true rather than the facts [61-p 215].
Schemas and hierarchies are used to recall learned material by inference [61-p 223].Learning and retrieval are context sensitive as well as related to the feelings at the time of learning [61-p 229] (easy to recall happy memories when happy etc.).
**"Subjects can develop effective procedures for performing tasks without an ability to explain what they are doing" [61-p 235].**

**The essential elements of problem solving [61-p 237] are:**

- **Goal directedness**. Goal state.
- **Sub goal decomposition**. States along the way.
- **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).
  Means to ends analysis (Tower of Hanoi), 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.

**Three stages of skill acquisition [61-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 improvement in performance of a cognitive skill tapers off with practice according to a power law and shows modest decline over long retention periods.

**Two types of knowledge [61-p 280] are identified declarative (information) and procedural (actions).**The process of conversion between factual information to a set of actions that accomplish the goal is termed proceduralisation.
**Tactical learning** [61-p 283] is a process where specific rules are learned for solving specific problems.
**Strategic learning** [61-p 285] implies developing or acquiring methods of organizing problem solving so that it is suited to a particular domain.

**The ability to create new constructs for representing the key aspects of a problem is a sign of growing expertise [61-p 292].**
**Another sign is the ability to recognise 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 (chess players are not good general thinkers) even if the areas are similar and it is worse for domains that are not similar.
**In the case where a skill becomes obsolete (algebra shortcuts when calculators are introduced) people still tend to use the old shortcuts.**

**Skill transfer is improved when the underlying knowledge elements are identified and abstracted so that they can be transferred to many areas of performance [61-p 299].** Intelligent computer tutors can facilitate rapid mastery of complex skills, by students, by monitoring and providing feedback on individual components of skills.

**The Mental Model theory of Johnson – Laird (1978, 1983) [61-p 321] is mentioned and summarised in terms of how people create mental imagery to interpret and evaluate syllogisms.**

**People make decisions under uncertainty in terms of subjective utilities and subjective probabilities [61-p 337].** The way by which the problem is framed influences the decision when there is uncertainty [61-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 [61-p 341].

People tend to pause after each meaningful unit of speech.
**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 [61-p 363].
The acquisition and processing of language is independent from other cognitive systems according to the modularity view.

**Comprehension** [61-p 379] can be analysed in three stages: the **perceptual** (how the words are originally encoded); the **parsing stage** (words are transformed into mental

representations); and the **utilization stage** (use if made of the meaning i.e. answering of a question etc.).

A distinction is drawn between a person's ability to **think better** or to **know better [61-p 421].**

**Neural development is more important to cognitive development before the age of two than after**.
**The rate of information processing increases with development [61-p 424].**
**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.**
**A distinction is drawn between crystallized intelligence (acquired knowledge) and fluid intelligence (ability to reason or problem solve in novel domains) [61-p 437].**
**Individuals may be expert in Spatial, Verbal, or Reasoning abilities. This means that they will try to problem solve in their preferred way [61-p 444].**

## 10. OVERALL COMMENTS FROM THE REVIEW OF "COGNITIVE PSYCHOLOGY AND ITS IMPLICATIONS"

In terms of this research the following information from Anderson's work reinforces and compliments the information obtained from Pinker's book.

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. This statement concurs with the main argument made by Pinker.

In performing its function the brain works in such a way as to first extract shapes from a visual scene and then recognizing the items extracted.
An object therefore is a gestalt of various segments of perceived information.
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 organisation of parts within parts.
It is particularly important to note "… that processes can become automatic with enough practice. When they do, devoting attention to them is no longer necessary and performance is no longer affected by the number of processes being performed simultaneously".
The brain is a complex parallel processing device.

Learning and retrieval are context sensitive as well as related to the feelings at the time of learning. “Subjects can develop effective procedures for performing tasks without an ability to explain what they are doing”.
The essential elements of problem solving are:

- Goal directedness. Goal state.
- Sub goal decomposition. States along the way.
- 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.

Three stages of skill acquisition 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.

Two types of knowledge are identified declarative (information) and procedural (actions).

The Mental Model theory of Johnson – Laird (1978, 1983) [61-p 321] is mentioned and summarised in terms of how people create mental imagery to interpret and evaluate syllogisms.

People make decisions under uncertainty in terms of subjective utilities and subjective probabilities. The way by which the problem is framed influences the decision when there is uncertainty. Success in the real world depends much more on deploying content-specific knowledge than on being able to correctly apply the rules of logic. 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.
Individuals may be expert in Spatial, Verbal, or Reasoning abilities. This means that they will try to problem solve in their preferred way.

## 11. REVIEW OF "FOCUSSING ON THE EMOTIONS OF DAILY LIFE, A GUIDE FOR THEIR MAINTENANCE" BY I SHALIF [46].

The review of this material 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.

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. It was necessary therefore to pay special attention to the operation of the emotions during the interviews with the controllers.

This review is significant because it presents in a concise form a list of emotion by-poles from which, by combinations, emotional states are created. By using this information prevailing emotional states during different work conditions were identified. A list of possible categories of organization of mental processes are provided in the reviewed material, as shown below. **This information compliments and in a sense summarises what was obtained from my review of the work done by Pinker and Anderson.**
Note: No page references are provided in this review, as none were included in the material reviewed. However the information presented below is done more extensively than the two preceding sections.

In his work, Dr Ilan Shalif states, **"The real motivation behind all human activity (our own included) 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". He continues by pointing out that we are not really used to paying attention to or identifying our emotional states and those of others, particularly for those of us that uphold the erroneous split between logic and emotion. Under the term "emotion" he includes moods, feelings, sensations, subjective experience, passions and the like, all being processes of the brain.
These processes can be triggered by receptors at any part of the body or even from internal brain operations.

**There are tentatively about 15 basic emotions each structured as a bi-polar continuum, mainly operating through the "Limbic System" in the centre of the brain.**

**These are:**

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)**

The above list is not exhaustive as there is ongoing research to identify further categories. **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".**

A bipolar, more advanced, type of biological structures produces 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.

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".

**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.**

**It is important to note that 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, due to stressful states, can have tremendous impact on the country as a whole.

Fluctuations between emotional states, resulting from complex situations, represent another way that emotions can hamper the controllers' performance.

Emotions are communicated non-verbally, even when we are lost for words to describe them, by means of tonality, facial expression and body posture.

Emotions start as “innate emotional programs” (Bowlby), which are then acted on by life experiences that modify the way that they are triggered and expressed. 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.

**The purpose of the emotional experience as defined above has 10 main facets.**

1) When intense **it concentrates the attention** and other resources of the individual to deal with emergencies. This has been shown in an EPRI report as well, however it was also shown that as stress increased beyond a particular point the controllers’ concentration dropped rapidly.
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. Moods are based on mostly erroneous judgements and illogical conclusions. They can be like alarms that have not been reset creating the illusion of ongoing danger.
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. The controllers have corroborated this last point as well. They have repeatedly stated that their assessment of the ESKOM network has a very strong emotional component that prompts them to act to bring about corrective adjustments.

Finally he states **“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”.**

This means that we are not directed to achieve specific aims but to preferring certain emotional qualities. 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.

**The emotional experience depends on the interaction of the following systems of the brain and mind.**

**Basic Emotional Structures**.
There are about 15 to 20 neurobiological structures of the brain as listed above.

**Input.**
This is the process of transferring energy, mater or information or all of them from one source or various sources over any time frame to any destination that is capable of receiving it.

**Feedback.**
This is a process by which a portion of an output of a system is fed back to that system as an input in such a way as to have an effect on that output. When the result is such that the output is increased it is referred to as positive feedback, whereas when the output is diminished as a result of the feedback it is called negative feedback.

**Activation Programs.**
These start as innate primitive programs (that act as the building blocs for activation programs as well as to take over in an emergency when swift action is the preferred mode) and later develop into proper activation programs by conditioning. They are patterns for the activation of processes in the mind and body, stored in the memory.
Ad-hoc programs that are dealing with the situation at hand normally activate them.

**Ad-hoc Programs.**
These are temporary versions of the semi-permanent activation programs (J Piajet) and old ad-hoc programs as per the demands of the moment.

**Supra-programs.**
These are new (as opposed to innate) programs built over time. They are stronger or of a “higher status” than the innate ones. In most circumstances they inhibit the innate ones or actually substitute for them. What distinguishes them from innate ones is that attention, in the elements that form them, is required by the individual. The importance of attention in the formation of these supra-programs (and as a result the importance of the intensity of emotional states) is very relevant to the work done by the controllers at ESKOM. Other “building materials” are: contemplation, imagery, passively absorbed information, learning, activation of programs in a “theoretical manner” in the imagination without their behavioural components, pressure from

external sources etc. These supra-programs are more complex and more flexible than the old innate ones.

**Emotional Programs.**
Though all programs are related to survival and thus to emotion not all of them are coloured so much with emotional factors accessible to awareness of the individual or to those who observe him. It is common to distinguish between the two kinds and call emotional those super-programs that have obvious emotional manifestations or that defy simple logic. Basic emotions can be activated from internal operations by (changing the content of our thoughts), this a learned ability that adults acquire. However this ability can be a double-edged sword when the process goes on unchecked as when imagined danger debilitates a person. The innate behavioural alternatives that are used to create changes of the emotional climate can be grouped into four categories.

1. Natural behaviour. As in eating when hungry etc.
2. Appropriate behaviour. As in crying when sad etc.
3. The regard of emotional states as prompts for action. As in fleeing when frightened.
4. Treating the emotion or sensation as an invitation to pay attention to it.

**Cover programs.**
These programs divert the attention and the emotional experience from its “natural” course. Their purpose is to weaken or suppress altogether, change the quality, intensity, or other aspect of the emotional experience. Unsophisticated ones prevent emotional experience from reaching the awareness at all. The more sophisticated ones selectively prevent, modulate, or divert emotional experiences. They are most dramatically expressed when they are on the verge of failure. Often an intense fear manifests in order to divert the attention from what appears to be a “dreaded secret” which the cover program is trying to hide. Anxiety attacks are the common means of their manifestation. They usually lead to an emotional bankruptcy of the individual, as no “emotional cost” is too high in order to “cover” that which they must. These programs however do not remove innate and other basic emotion programs. It seems that the various supra or cover-programs only contain the ability to shorten, diminish and push to a subliminal level certain parts of the innate programs, the cover programs carrying greater weight. Cover programs are not necessarily bad as they are used to filter information that would otherwise overwhelm the attention.

**Cognitive processes.**
This is a term used to define higher-level processes the products or results of which are accessible to the awareness and logic or potentially so. When they involve mostly thinking or verbal conceptualisation they are referred to as “cold cognitive

processes". When emotions are prominent they are referred to as "hot cognitive processes".

**Subliminal perception or sensations.**
These are terms used to define the input of a process to a subsystem of the awareness when it does not engage our consciousness.

**Trash-programs.**
In this category are included programs that do not support the wellbeing of the individual.
They are important but malfunctioning supra-programs, which were constructed during a person's life, that are no longer valid.

There are about six main "families" of those "trash-programs". Sometimes, a subprogram or even a whole program can be allocated to more than one of the following groups or families, as they are not mutually exclusive:

1) The most prominent family consists of programs which are responsible for prolonged pressure, distress, depression, tension, stomach pains, heart discomfort, low back pains, etc.
2) The second family consists of programs responsible for the relatively short and acute emotions and sensations such as: anxiety attacks, rage attacks (accompanied by the will to hurt the offender), sporadic guilt feelings, shame, weeping, etc.
3) The third family consists of those programs that prevent the experience and/or communication of the felt emotions, sensations, moods, passions, etc. or at least attenuate their intensity. A few members of this family are indiscriminate and affect all levels and qualities of the emotions. The others are a bit more discriminate and have a more selective effect on the various aspects and expression of emotion.
4) The fourth family is the most destructive. Its members prevent us from executing essential behavioural patterns, or restrain us from executing actions we have already decided on, even when we know that they are vital to our well being. The affects of these programs are usually felt as "internal resistance", inhibitions, lack of will power, personality factors and characteristics, etc. These programs delay, postpone, hinder, or even prevent the beginning of the execution of programs and plans. Sometimes, in addition or instead of the above, they "just" sabotage their progress.
5) The fifth family consists of programs doing the opposite with nearly the same damaging effects or even more. They execute prematurely behaviours we have already decided to delay, postpone, or even wish to prevent. They prevent us from the timely aborting of behaviour and other actions found faulty during their execution. Programs of this family can

"take us for a ride" that could be prolonged for life, or shorten our lives to suit their length.

6) The sixth family is the biggest of all. It consists mostly of emotional supra-programs that cause erroneous evaluations of circumstances and resources. The programs of this group are of three main kinds:

   - Programs that introduce errors that are relevant for one of the basic emotions.
   - Programs that cause errors in certain circumstances that are relevant to mixtures of basic emotions.
   - Programs that are responsible for widespread distortions in the emotional testing of reality.

Why are programs trashy?

There are many reasons why we have trash-programs:

1) First and foremost is the huge number of programs, chunks of information, and other impressions stored in our memory that we have to deal with:
   a. We have a substantial number of innate programs that are hard to mould into more advanced and divergent forms.
   b. We have a nearly infinite number of memory traces of the activities of ad hoc programs registered, which we have to refer to when relevant problems are encountered.
   c. We have a rich environment that changes constantly. This brings us face to face with new opportunities and dangers and forces us to build and maintain a multitude of additional programs, most of them not executed in real life even once.
2) Second in order but not in importance, is the limited capacity of our brain and mind processes responsible for the updating, mending, accommodating and adapting of the supra-programs of the mind.
3) The third reason is the built-in strategy of the brain and mind system when confronted with the "impossible mission" of managing real life.
   Because of these limits, most of the adaptation processes are initiated by it only when ad hoc programs are built, whether for internal use or for actual behaviour. (If the system tried to update, mend, accommodate, and adapt all programs stored in memory, we would be stuck with those of the first months of life!!!)
4) As we have built by ourselves, copied from others and been given abundant examples of programs, which were trashy to begin with (as they were built from far from perfect components), the complete adaptation of even one program seems to be impossible.
5) People around us are usually interested in what we are doing and feeling. It started even before birth and will usually continue, even after our death. As a

result, part of them built in us programs on purpose, for their good, or for ours, because of cultural demands, and because of their own various trash-programs. In many cases their effect on our programs was just accidental or even random.

6) One of the most important factors that contribute to the trashiness of our programs the more emotional and the less emotional ones are the cover-programs. For many reasons, these programs prevent or limit the involvement of the awareness in many programs, contents, and felt sensations of the body. When access to the awareness and its attentional resources is limited, the application of the amendment processes to the trash-program is also limited and the level of their trashiness remains high.
7) We nearly always neglect the only opportunity we have to make things a bit more bearable due to laziness, prejudice and ignorance, i.e. we do not "listen" to the "begging" of the control routines of the active ad hoc programs, which request the addition of attentional resources, even when submitted as clearly felt sensations.

**Common Roots of Trash-Programs**

The following are a few of the most prevalent "replicas" or contents of messages of socialization agents. They were surely recited to you many times. Even if you cannot recall the fact and even if you missed a few, they are very good material for self-provocation intended to summon felt sensations for focusing purposes.

1) Do not feel emotion X!!! (Here and in the other items, synonyms and "relatives" of the word "emotion" are applied too.)
2) Why do you not feel emotion Y?
3) In situation X you should feel emotion Y and not emotion Z.
4) In situation X substitute emotion Y for that of Z.
5) Change emotion X with the substance Y (food, drug, beverage, etc.).
6) After emotion X comes/ must come the emotion Y.
7) Emotion X is not proper for one who is male/female, and whose age is Y and his social status is Z.
8) Refrain from too high/ low intensity of the emotion X in situation Y in the presence of Z.
9) It is better not to execute behaviour X or express Y in situation Z.
10) If you do X you should/ would feel Y instead of Z.
11) Refrain from behaviour that causes a discernible measure of emotion X.
12) In situation Y change the emotion X into its opposite.
13) Instead of doing X, feel Y.
14) Instead of feeling X, do Y.
15) See what emotion X you are causing me.
16) Do not be/ behave like a baby.
17) Do / stop doing X which results or intends to cause emotion Y to Z otherwise....

In summary, we have **activation programs; ad hoc programs; supra-programs; emotional programs; cover-programs; and trash-programs**. It seems that the relation between the primary emotional programs of the mind and brain system, and the supra-programs are like those of democratic parents and their young offspring. Most of the time, such parents let the children decide for themselves autonomously, though only within their protected environments (demarcated by the cover-programs). Meanwhile, they wait in the background to help or assist in emergency situations, and all the time they murmur to themselves and those around them remarks, and comments, compliments and criticism (the low intensity sensations of the body that are always felt by us).

The survival of the innate programs, and the dynamic interactions and combinations between them and the supra-programs of adults, express the little importance nature gives to our learning abilities and reasoning faculties.

**In the usual course of life, the less emotional supra-programs are active in the foreground, while just behind them - at the margins of awareness act the more emotional ones and in the far background "lurk" the always-active primary innate emotional programs - as if according to "the rules" and "orders" of "natural selection".**

The contemporary state of affairs is like a verdict that says, "similar to other animals of a high developmental status, the members of the human species are primarily emotional beings". It seems that man functions better as Homo-Emotionalis than as Homo Sapiens. **Nature still prefers to rely heavily on the Limbic System (the older part of the brain) rather than on the Cortex (the outer layer of the brain which is a relatively newcomer) - and more so in an emergency.**

Even in adult human beings, whose cortex and logical thinking is developed to the utmost, "nature" has reservations. It does not give man's rational processes of reasoning absolute control, even for a moment. Even with adults, the "new" parts of the brain, the conscious thinking, and the emotional supra-programs, function only as supplements to the innate primary emotional programs and not as substitutes.

However, when no emergency provokes the primary emotional programs, the emotional supra-programs seem to have nearly sole responsibility. Only when we consider this, can we understand how the most sane and intelligent persons may be aware of an activity of theirs, that contradicts both logic and self-perseverance, and still continue with it.

Only when considering this can we understand how people can consciously observe without intervention, or even initiate, behaviour that defies logic and may endanger

their health. It is most conspicuous when human behaviour entirely contradicts the survival prospects of both the individual and his nexus.

Reckless driving, volunteering for dangerous sporting missions, introducing harmful materials into the body like drugs and junk food, refusing to take urgently needed medicine when ill or even to see a doctor - are only the most common and most obvious of the trashy activities of defective supra- programs.

Usually, behaviour that defies logic and endangers survival will be enacted when there is a contradiction between short-term and long-term-considerations. The logical considerations and life experience which use the supra-programs to influence the primary programs of basic emotions are often not strong enough, when the innate ones pull in the
opposite direction because very short-term- considerations. The many failures of logic to influence the behaviour of individuals, groups, and even nations emphasizes the fact that "human nature" is still Homo-Emotionalis and not Homo-Sapiens.

Constantly, programs of various levels of "trashiness", manage our life. Constantly, the control routines of the ongoing ad hoc programs try to recruit more mental resources in order to adjust to the demands of the present. Constantly we do not give enough attention to the felt sensations of the body, which are mostly notices from these programs, as if to keep the level of trashiness from descending too low. Luckily, we pay scant attention to these demands - and thus prevent life from sinking too deep into the garbage pile.

There are various ways one can treat or relate to the trash-programs that create or are responsible for unpleasant feelings. These measures and points of view are also applicable to the programs that push us to behave in contradiction to what our reason and the supra-programs that are not so faulty try to tell us.

The most common views are those of the defeatists. They regard the mission of improvement as almost impossible. Each encounter with a faulty activity of a program leaves them feeling helpless. Eventually, the recurrent feelings of helplessness are established as a trait.

The less common - though it is the most simple - is the stubborn approach. This way of looking at the problem is common to the innovators, the adventurists, the rebels, and the author of this book. In essence it says: "do not yield". It conveys the stubborn decision that it is worth trying to change the whole world and especially the emotional supra-programs of the trash type, in order to make life a pleasant voyage on earth - while life and earth last.

## 12. OVERVIEW OF FINDINGS FROM SECTIONS 4 TO 11.

It is clear from the above material (all three reviewed sources) that the "human software" underlying 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 structure in which it operates are stratified in "layers" some of which are outside awareness. It is some of these layers, of mental representation, that this research has sought to reveal. These will be presented in the Findings section, Appendix C.

## 13. REVIEW OF THE NEURO-LINGUISTIC PROGRAMMING (NLP) FIELD [46-59].

In this review the various aspects of the **human expertise modelling process** were identified and are summarized below. Of particular significance is the **"Metamodel"** process, which was used to reveal hidden layers of **meaning** in what the interviewed controllers said. The **sub-modality** elicitation section is also very significant as it was used to reveal the structure of mental representations (whether the controllers visualize in colour or black and white imagery etc.).
As indicated at the beginning of this section, I have many years of training in NLP and have applied it in many fields, particularly that of education.

**THE MODELLING PROCESS**

As identified from the various references cited [52 (chapters 1-4, 6), 54 (chapters 1-3), 57 (vol. I chapter 15, vol. II chapters 15 & 16)], the stages of modelling human expertise can be summarised as follows:

- **ELICIT** relevant data, and gather information from expert / s.
- **FORMALISE** information and structure the model of expertise.
- **TRANSFER** 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 structure of what they do so well.

**The stages of learning [55-p 24] 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 expertise).

If the person modelled is an expert, expect them to be in the second last category. It will be the task of the modeller to move them into the last category. 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.

**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 intention of the subject.

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

- Are you modelling behaviour, 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 of the above methods were used in the interview process.)

- Is the level of detail of the information elicited appropriate to the outcome required? To determine this, consider the prevailing external and internal factors as well as any constraints.
- How will the data be formalised, by what means and on what level of detail?
- How will the model be transferred after it has been formalised and to whom? Will it be in the form of:
    - Live presentation;
    - Manuals;
    - Audio visual;
    - Interactive media;
    - Expert systems;

- On paper; or
- Mixed.

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

**In preparation for elicitation, note the following requirements for yourself:**

- Be clear about what it is that you want to elicit, yet flexible enough to allow other important issues to come through.
- Ensure that you can use all your sensory channels.
- Establish a way by which you can maintain your focus on the other person and not drift into thoughts of your own.
- Establish ways by which you can maintain your energy level during the interview process.
- Establish ways to either associate or disassociate from the subject.
- Ensure that you meet the individual you are interviewing at their model of the world.
- Be familiar with the jargon of the field in which the person you are interviewing works.

**During the interview process it is possible to go from:**

- **Macro** aspects:
  - values
  - beliefs
  - linguistic metaphors
  - sorting styles
- To **Micro** aspects:
  - strategies
  - modalities
  - sub-modalities

In each case notice the internal and external, conscious and unconscious, overt and covert aspects of the subject's experience.

Choose the format (mind map, lists etc.) and the material you will use (note pad, flip chart etc.) to log the following dimensions of the modelling subject.

The terms below refer to what as known in NLP as "logical levels" of organization of experience or "neurological levels" [55, p28]. This view is also presented in Pinker's, Anderson's, and Shalif's 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; these states as a collective define an individual's identity and that identity is then considered as part of a greater context or whole. This is by no means a linear process as the brain is a marvellous parallel processing entity with many multi-connected layers (conscious and unconscious) operating at once.

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

**BEYOND IDENTITY** This level represents an individual's "connection" with structures beyond his / her sense of individual self (i.e. family, ethnic group, etc.).

**IDENTITY** This refers to the controllers' sense of identity within the control room environment. "Who are you with respect to the network?" was the question asked. During the interviews the controllers' sense of identity outside the control room was elicited so that it can be compared to their sense of identity within the control room.

**VALUES** I elicited that which each controller values, with respect to their work and other experience. What they fear was also considered. The value of something is defined as the "state" that it creates within an individual's mind. In this respect see the literature review under "emotions" [60-63]. Shalif [62] 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" is a typical question asked in order to elicit values.

**BELIEFS** 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:

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, as well as the NCC as a working environment.

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 (sort through = filter) through which information passes. Controllers were asked to indicate what it is that they sort for.

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

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". In this research the metaphors that the controllers used were explored in terms of the implied associations inherent in them.

**LINGUISTIC METAPHORS**

In this respect, the following types of questions [48-49] were asked: "What is the network like?" "How do you relate to the network (externally and internally)?"

By asking such questions a story or a theme with characters etc. arises, from the controller's unconscious. This is distinctly different from ordinary technical descriptive 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, [46, 52, 54, 55, 56 & 57] set of questioning techniques, as proposed by Grinder, were used. These questions revealed the complex equivalences of words by facilitating searches within a person's unconscious.

**METAMODEL**

This represents a method of identifying and overcoming the linguistic violations listed below. It involved asking specific questions in such a way as to reveal the hidden, deeper level, meaning of the words that the controllers used. By using this technique during the interviews the controllers' inner abilities, beliefs, values etc. were identified. The list of terms below is defined in the literature [55, p140-141].

**Deletion:** (Important information is left out and this limits thought and action.)
Simple/Comparative Deletion;
Unspecified Verb;
Unspecified referential index;
Judgements;
Comparisons.

**Generalization:**
(One example of a class is taken to represent the class, in ways that narrow possibilities.)
Modal operators of necessity;
Modal operators of possibility;

Universals.

**Distortions:**

(Information is twisted.)
Nominalizations;
Mind reading;
Cause and effect;
Complex equivalences;
Presuppositions.

The other very important aspect of the interview process is the **modality and sub-modality elicitation** [46-59]. In the Metamodel section above, what was pointed out was that there are many layers of meaning in the spoken word. What was considered next was that the structure of meaning itself is rooted in experiential components, the senses [60-61, 46-59]. 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.
We normally think of five primary senses (visual, auditory, kinaesthetic, olfactory and gustatory), even though there are others, i.e. balance etc. For the purpose of this research the visual, auditory and kinaesthetic senses were only considered, as these are the ones mostly relevant in the NCC environment.
In this section the sensory structure of the meaning of words was elicited. 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**

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 deep-structure 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 (its sub-modalities) etc. In this way the controllers' mental worlds were explored.

**SUB MODALITIES** These represent the constituent structural components of the sensory modalities mentioned above. Here are some examples:

| | | | | | |
|---|---|---|---|---|---|
| Black | Bright | 3D | Distant | Movie | Associated |
| White | Dim | Flat | Close | Still | Disassociated |

| | | | |
|---|---|---|---|
| Tone | Constant | Movement | Location |
| Tempo | Intermittent | Pressure | etc. |

For each modality I explored the sub modality structure of each individual's experience (this was a slow process that required a lot of patience). Having sought permission, layer after layer of the structural components of the mental representations used by the controllers was uncovered.

In this section the sequence aspect of the structure of experience or expertise was identified [46, 52, 54, 55-59]. 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" zoom into a particular section etc.

**STRATEGIES** These are the **sequences** of Visual, Auditory, Kinaesthetic, Olfactory, Gustatory as well as the Test, Operate, Test, Exit (TOTE) [52, 54] patterns of experience. The sequencing of a controller's internal processing can be identified and used to custom design suitable computer interfaces, train others etc.

The meaning of verbal communication largely lies in intonation and body posture (as much as 93% of it [56]). As a result special care was taken to notice subtle, unconscious, movements for clues to the underlying states of the words used by the controllers.
Often, what was being conveyed by a person's physiology was truer than what was being revealed through their words. In this respect the video material was invaluable. What I looked for was a state of congruence between what was being said and the speaker's physiology. Incongruencies were explored as far as possible (even when it was ff camera).

I considered the following:

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 physiological aspects that were considered are:

**PHYSIOLOGY** Breathing Location of tension Muscles Eye Blink

Gestures Posture Head Nods Head Location

Mouth movement Hand movements etc.

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 in particular was added to the material used for this section [62-63].

**EMOTIONS** A list of the basic emotions (see literature review), each with their two poles and a seven point scale in between them, was be presented to the controllers. They were then asked to map out their emotional state in three different situations:

- **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 controllers' descriptions of "emotional energy" flow (authority, power, love, coercion, etc.) among the control room staff was noted.

The ability to have "perspective" on a situation depends on how a person is "positioned". 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.

It was part of the research to find out if controllers have these skills. In the NLP context these skills are referred to as perceptual positions they are:

**PERCEPTUAL POSITIONS**

In relating their experience the controllers will be in one of the following perceptual positions.

**FIRST** (Describing events through their own eyes).

**SECOND** (Describing events through the eyes of another person).

**THIRD** (Describing events from a distance, looking on the events described).

These perceptual positions were noted and their significance was explored.

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.

**TIME**

The time orientation of the controllers will be noted as **PAST, PRESENT, or FUTURE**. Hand locators or other expressions and gestures for past, present, and future were noted.

**ANY OTHER EVIDENCE**

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; music; environmental factors; demonstrations; representations; buzz words; jargon; equations; manuals; artefacts; symbols; tools; software / hardware; photographs; clothing and wearables; food stuff; traditions; rituals; rules; technical knowledge; theories etc.

# APPENDIX B

# GENERAL BACKGROUND

**In this section the following are described:**

- **The national control room;**
- **The personnel that work there as part of a control shift;**
- **Difficulties and problems experienced at NCC; and**
- **The three research questions.**

## 1. THE NATIONAL CONTROL ROOM (NCC)

The NCC comprises of a circular control room in which a number of staff interact with a variety of computer displays and consoles. The abovementioned staff members, or controllers, are responsible for the coordination of supply and demand of electrical energy from the various centres of generation to the different load centres around South and Southern Africa. This power transmission is done via the national grid of high voltage power lines, sub-stations etc.

**Within the control room there are:**

- **A Wall Display (W D)** panel on which the entire transmission network is shown. This wall display is at the front of the control room. It is not used much during normal control operations but is used for network restoration in the event of a black-out. This new wall display, in the front of the control room, shows the transmission network vertically. This is different from the older one, which had a horizontal orientation. This new display has an upward turn in the grid layout that depicts the Western Cape region in a way that does not match geographical reality. More importantly however, it does not match the way that the network is being depicted on the desktop monitors that the controllers use for all of their work.

- **A Transmission Control Desk (T C D)**, which is used for controlling the switching of power lines for maintenance and any other prearranged activities. The work carried out on this desk, involves prior arrangements and authorizations in order for lines to be handed over to the various regions during the beginning of a day and returned to the network when the scheduled work is completed. The regions request the lines, a schedule is drawn up which is then approved, the lines are handed over following very specific procedures and are returned to service, again following rigorous steps that ensure the safety of the network and those that work with it. All these processes take place over many hours and as a result there is very seldom a sense of urgency about the work done on this desk.

- **A Loading Control Desk (L C D)**, which is used for active power and system frequency control. The flow of active power depends on the relative

phase angle between the voltages of two stations or busses. This relative phase angle is determined by the speed of the generator rotors (this in turn depends on the mechanical power supplied to the generator turbines) at power stations and the load demand at the various sub-stations. When the supply and demand of active power are equal the system frequency is constant. The system frequency must be kept constant at 50 Hz (+/- .
The function of increasing or decreasing generation, in response to national load demand profiles, involves a fair amount of automation, in the form of preset limits within which the power stations' output is regulated. Further, historical information is used to set the operating parameters for the up-coming periods. As a result, the role of the human controller is such as to oversee the whole process so that the national supply frequency remains within 0.5 % of 50 Hz. On this desk as well, the time frames involved are quite long, that is because even if the frequency drops below or rises above 50 Hz there is plenty of time to rectify the situation by engaging extra generation, load shedding or reducing generation as the case may be.

- **A Voltage Control Desk (V C D)**, which is used for voltage level and reactive power flow control. The supply authority, ESKOM, is obliged to supply its customers with a fixed voltage level that is allowed to vary by a maximum of 10 % above or below nominal. Active and reactive power travelling from the generating points to the loads causes volt drops along the power lines through which it travels. In this respect it is not only the magnitude of the transferred active and reactive power that must be taken into account, in order to maintain voltages at the load substations within legal limits, but also the route that the said power takes. Further, the flow of active and reactive power do not happen in the same direction, as reactive power can be generated by other means than power station generators (capacitor banks, the power lines themselves, certain types of load etc.). This makes the control of reactive power flow much more complex than the flow of active power. The direction of reactive power flow is mainly dependant on the relative value of the voltages between two stations, so that voltage control is intimately linked with reactive power control. To make matters worse the voltage in a particular area (there are certain regions that are more critical than others) may reach a point where it collapses very rapidly, unlike the drops in system frequency that happen much slower, particularly when there are contingencies such as lines that trip etc. The work on the voltage control desk is therefore much more complex and urgent than on the other two desks, as seen from the information above together with the fact that there are no automated procedures or historical information to go by. Moreover, because different power lines can be in or out of commission, the prevailing weather patterns keep changing, there can be farm fires under lines or other unforeseen events may take place at any time the voltage control function is made even more varied and taxing.

Because of all these factors, a controller will only be authorized to work on the voltage desk after he or she has spent many years on the other two desks.

- **A Shift Manager's Desk (S M D),** which is used for the overall supervision of the control room. The shift manager carries the final responsibility for all the activities and actions of the controllers.

- A few **other desks** (A second Transmission desk, a Plant Condition Monitoring desk, a Commissioning desk, and an Automatic Generation Control desk) that serve secondary functions. These other desks are only used during the day by staff that does not work shifts.

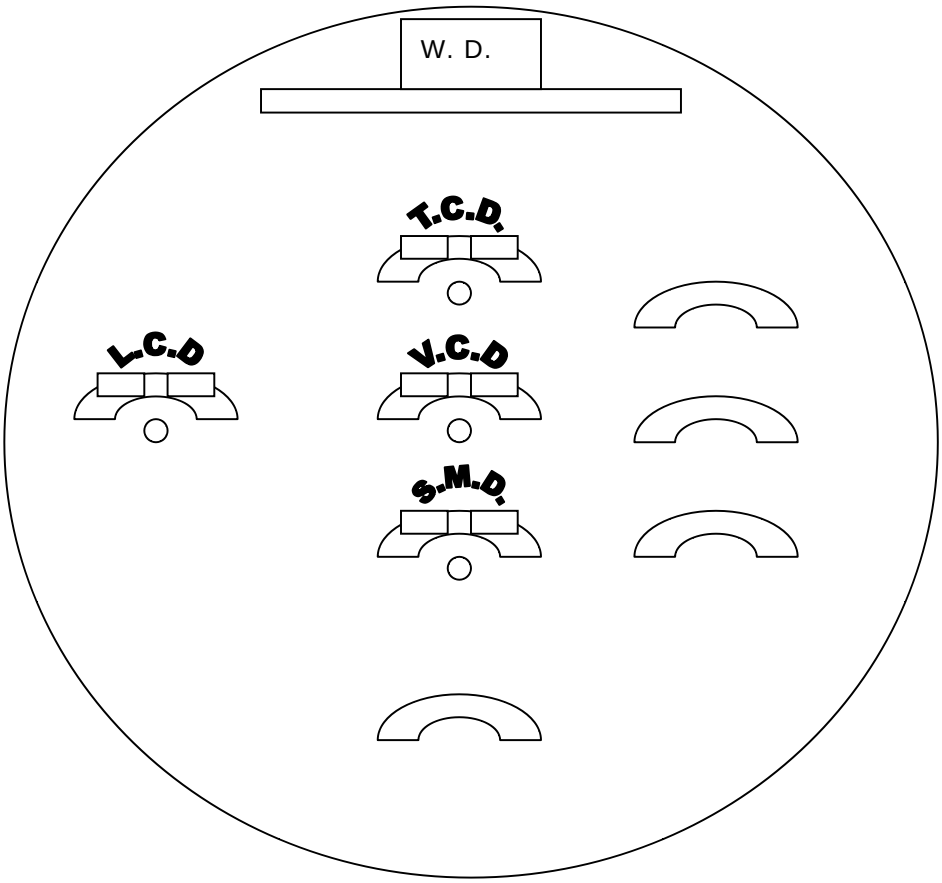



**Fig. B1.** National Control Centre, Control Desk Layout (floor plan).

## 2. CONTROL ROOM PERSONNEL

To perform the main control functions there are at least five members present in any one twelve-hour shift. Shifts run from 7 AM to 7 PM every day.
There are five shift groups of five or more people each. These shift groups are deployed on different days in a month so that there are many days set aside for time off, training etc. according to a predetermined timetable. It is worth noting that some years ago, the shift duration was eight hours and there were three shifts per day. However, the current system is favoured by all concerned.

In order to carry out their function the controllers need to have a variety of technical information about the capacity of the generation stations, the level of power demand and its fluctuations, voltage levels at all national grid busses, reactive power flow, weather conditions and other environmental factors as well as the state of "health" of the grid. All this information is presented by computerised displays in the form of single line diagrams, numerical values of critical variables, various alarms, in writing, over telephones and in person.
This complex real-time flow of information has to be interpreted by the controllers. They then make complex decisions to ensure the safe and continuous operation of the whole network, within predetermined parameters. The network includes South Africa (the national utility, ESKOM, is one of the largest in the world) and links with Namibia, Zimbabwe, Botswana, and Mozambique.

It is interesting to note that many people "outside" the control room hold the view that the controllers stand apart from the network and "control" it, very much like a machine or a motorcar. However those actually doing the work regard themselves as part of the whole system and therefore "feel" it and are affected by it. This view was expressed by the controllers during their interviews.

**The five members of a shift are:**

- **A Shift Manager (SM)**, that carries the overall responsibility, has the final say on all matters pertaining to the operation of the network and does the least amount of actual hands on work. The shift manager has many years experience both in the control room as well as in the field outside NCC and has passed through all the roles listed below. His position demands more than just experience however, he has to be a leader and must be able to make decisions about all the functions in the control room. His job probably caries the highest stress level as is indicated by health statistics.

- **A Senior Advisor (SA),** who is an overall control expert. He is authorized on all the desks, has passed comprehensive testing on the job as well as on the simulator, and has extensive experience both in and out of NCC. He is senior to all in the control room except the shift manager and will stand in for him in

his absence. He is involved with hands on work on all the desks but mostly works on the voltage control desk.

- **A Voltage Desk Controller (VDC),** who is responsible for monitoring and controlling the voltages at all the substations in the country that operate at transmission voltage levels. His / her job is to maintain the voltage levels within legal limits by adjusting the flow of reactive power and if need be shedding active power load. His job involves working with two computer monitors, two keyboards, and a mouse. He also has to use a telephone for communication with power stations and other operatives in the field. He may work together with the senior advisor and reports to the shift manager. He gets busy during load profile changes that take place at evening and morning peaks. It is important that he / she remain proactive and anticipate contingencies before they arise. His control actions are:

    - To instruct power stations to deliver or absorb reactive power.
    - To switch capacitor banks and other passive reactive devices in or out of the network for local reactive power regulation.
    - To switch power lines in or out to redirect the flow of power or strengthen power corridors and control volt-drops.
    - To shed load to maintain the overall integrity of the network.
    - To island areas during contingencies to prevent voltage problems from spreading from one area to the next.

    He is also responsible for generating reports on a daily basis and recording all the switching actions that he performs.
    As the network itself and the conditions under which it operates are not fixed this person has the most versatile and dynamic role to play in the control room. His job urgency level is high as conditions can change rapidly. However most of the time (particularly between the evening and morning peaks) very little happens.

- **A Loading Desk Controller (LDC),** his / her job is to balance the supply and demand of active power by means of setting upper and lower limits of generation for power stations. These are adjusted from load profiles obtained in previous years and by taking into account financial considerations. He instructs the power station controllers to increase or decrease load outside of the above-mentioned preset points. His operating reference is the system frequency that has to be maintained at 50 Hz.

- **A Transmission Desk Controller (TDC),** whose job is to be responsible for handing over and putting back into operation power lines and other transmission equipment. This is done according to preset procedures as mentioned above under the Transmission Desk heading.

Over and above the five members mentioned above, there maybe one or two, at the most, employees being trained at some of the desks.
It is standard practice for a trainee to start at the Transmission Desk, then move to the Loading Desk and finish off at the Voltage desk which is the hardest one to master.

**In general terms what is required in order for the ESKOM National Control Centre to fulfil its purpose is as follows:**

- There has to be a **functional power grid,** this includes generation, loads and the interconnecting network (primary and secondary plant).
- There has to be **real-time information** about its state, on a continuous basis (under normal and emergency condition modes).
- This **information** should be **presented** in such a way that it matches the controllers' preferred modalities (visual, auditory kinaesthetic etc.), as well their internal representations of the network so that the least amount of interpretation takes place. The ideal would be for the controllers to apply all their faculties in responding to the transmission network's operational requirements with minimum delay.
- There have to be **trained controllers** that can make sound decisions, in limited time frames, under dynamic conditions.
- The controllers must be able to **comprehend and** correctly **interpret** the information before them.
- There should be **predetermined procedures** and codes that guide / regulate controllers' actions and decision-making.
- Even though the controllers' actions are guided by procedures, it is necessary they should have a **sound understanding of the basic engineering principles** that govern the operation of the network.
- The controllers must be able to **foresee the consequences** of their decisions, on the whole of the network over appropriate periods.
- There has to be **cooperation** between controllers, both horizontal (at the same operational level) and vertical (from one level of authority to the next).
- The **controllers** should feel **confident** in their ability to fulfil their various roles and responsibilities.
- The **supervisors should have confidence** in the controllers' abilities.
- **Expertise** should be continually **transferred** from the more senior to the more junior controllers.
- The **transfer** of expertise has to happen **at a faster rate** than controllers passing through the system due to promotions, transfers, resignations, etc.
- The **control room environment** itself should foster an atmosphere of well-being and cooperation where the majority of the controllers feel alert and supported to make the best possible decisions. It should be kept in mind that

emergencies are not the order of the day and that the control room environment is a rather quiet place most of the time.
- Controllers should experience **fulfilment** in their job and they should be happy to make it their career (low staff turnover).

## 3. DIFFICULTIES IDENTIFIED AT NCC

During preliminary interviews, in 2002, with senior management at NCC, a number of concerns and difficulties were identified pertaining to the prevailing conditions within the control room environment. Symptoms of these difficulties manifest in a number of contexts. They are:

- Skills transfer and training;
- Staff upgrading;
- Integration between personnel and computer displays; and
- Information gathering during operating error investigations.

**The identified difficulties are as follows:**

1. It is a very real necessity for the national control staff to be able to **teach** their s**kills to one another.**
2. It is also necessary to remove, or considerably **reduce, the uncertainty from competence transference.**
3. Knowledge transfer should take place in such a way that **"depth"** is achieved.
   **Depth**: Correct real-time decisions as a result of the new controllers' ability to put theory into practice in a short time.
4. There needs to be a **trainer's perspective** instilled in the NCC staff members, particularly those more experienced.
5. It is necessary to **capture the knowledge in the heads of experts so that it can be transferred.**
6. **The new wall display in the front of the control room, (Fig. B1) shows the transmission network vertically. This is different from the older one,** which had a horizontal orientation. This new display has an upward turn in the grid layout that depicts the Western Cape region in a way that does not match geographical reality. More importantly however, it does not match the way that the network is being depicted on the desktop monitors that the controllers use for all of their work.
7. More information is required to **determine** what the controllers' **views are about the new circular (see Fig. B1) NCC** orientation as opposed to the old rectangular orientation.
8. Various, multi-layered configurations of network information representation are being proposed for implementation. **The relevance and desirability of** these proposed **computer representations need to be determined**.

9. There is evidence that **some** of the **procedures** in current practice have **not been instated with engineering principles in mind** (reactive power flow control sequences).
10. A **pilot training program**, which has been created for Network Controllers within the NCC, **needs follow up.** This is in order to determine if it meets all the requirements of the people that it is aimed at.
11. A number of concerns have been raised about the controllers' **reluctance to accept proposed computer representations** of the network and its stratification.

The concerns listed are quite varied, however upon closer inspection it can be seen that there is a **common thread** that runs through most of them. This common thread is that very **little is known about the way(s) that controllers process information within their minds to arrive at decisions**. Further, it is not clear what the differences are between the mental representations, of the grid, in the minds of older experienced controllers when compared with those of the less experience.

The purpose of the research, then, is to investigate the processes and content, of the mental interpretations that the controllers use when going on about their work.

**Only the controllers working on the Voltage Desk (being the one that requires the most interaction between controller and network) were considered for investigation, in order to limit the scope of the project to a manageable size.**

## 4. THE RESEARCH QUESTIONS

After considering all the above information three interrelated research questions have been formulated.

**The research questions asked are:**

- **How do the Experienced Voltage Desk Controllers do their work? What are their external behaviours while working? What are their mental representations, strategies, and visualization of the network?**

- **How do the New Voltage Desk Controllers do the above?**

- **What are the similarities and differences between an MMI developer and the two groups above? How do they view and interact with the network?**

# A P P E N D I X  C

# M E T H O D O L O G Y

**In this section are included:**

- **The overall methodology used to conduct the research: and**
- **The methodology used to conduct the interviews with the controllers.**

## 1. METHODOLOGY OVERVIEW

The following methodology was used in order to answer the research questions. One of the steps in that methodology is the method of the interview process itself.

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

1. Preliminary discussions were conducted with NCC management to determine their needs. These initial interviews were simple and informal.

   **Outcome: List of needs and finalization of research proposal.**

2. Preliminary discussions were held with controllers.

   - The controllers were informed about the three research questions.

   - Then, there were informal discussions to establish rapport and to hear first hand what the controllers feel about their work and the problems they encounter. These discussions were held in the control room environment during day and night shift work over a number of days. The time spent in the control room 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.
   - From that, a needs list was drawn up with two categories of needs, those that pertain to the research questions and those that do not. The latter category was included so that other issues that may have bearing on the research could be considered.

   **Outcome: List of findings that helped to draw up the formal interview items.**

3. The needs that fall within the scope of this project were identified after all the findings from the above steps were considered.

**Outcome: Same as above.**

4. This information was conveyed back to all stake holders so that everyone knew what the project is about, what to expect as well what not to expect.

   **Outcome: Confirmation of participation in the project.**

5. A literature review was conducted to establish current practices. The literature review covered the following fields:

   - **Power engineering**. To identify practices and developments over time in the field of Power Grid Control Visualization [1-19].

   - **Industrial Psychology**. To identify elicitation methodologies [20-45]. Dr A. J. Thatcher of the WITS University Industrial Psychology department provided guidance. The method selected was Verbal Protocol Analysis (VPA). This method has been successfully used in previously conducted studies, in similar South African environments.

   - **Cognitive Psychology**. To establish a valid theory of mental processing [60-63]. An accepted theory of how the mind works was identified. The theory posits that unconscious processing is at the heart of decision-making and visualization.

   - **Neuro-Linguistic Programming**. To identify the techniques that reveal the underlying representations, visualisations, and mental models used by the participants [46-59]. The Metamodel process of eliciting underlying meaning of verbal descriptions as put forth by Dr J Grinder, and sub-modality elicitation form the basis of the interview process.

   **Outcome: List of papers, books, and any other materials identified in the course of the investigation.**

6. From the findings above, the structure of the interviews with the controllers was formulated.

   **Outcome: Interview methodology in appropriate format.**

7. Using the methodology developed in (6), a further series of formal interviews was conducted on an individual basis, to determine how controllers interpret and work with the network. This round of interviews was video recorded and was further analysed in detail.

**There were two parts to the interview process:**

- The first part consisted of video recording each controller working on a network simulator. As per VPA requirements, they commented on their actions while working.
- The second part, consisted of video recording each participant commenting on their simulator work as it was played back to him / her (retrospective VPA). Following this, the interview process continued using the Metamodel and sub-modality elicitation techniques by means of which their mental strategies and visualizations were elicited and video recorded.
- This was followed by a list of other questions as indicated further on in this section.

**Outcome: Data from two part interviews in unprocessed format.**

8. The findings from the interviews were analysed and the relevant strategies and visualizations were extracted, ordered, and summarised.

   **Outcome: Analysis and summarisation of performance strategies and visualisations used by controllers.**

9. Following on from the findings, a list of conclusions and recommendations was formulated and suggestions for further research identified.

   **Outcome: Conclusions, Recommendations that may improve work performance, and further research possibilities.**

10. Final written dissertation.

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

## 2. METHODOLOGY USED FOR THE INTERVIEWS

In this section the methodology used, for the elicitation of the participants' operating strategies, mental models and opinions about other maters affecting their performance, is described.

There are five teams of controllers (each comprising of five members) that run the ESKOM transmission grid and they work twelve-hour shifts. On each shift there is one person responsible for the operation of the voltage desk. That is the control desk from which the grid voltage levels, and as a result the flow of reactive power in the

different transmission lines, are adjusted and controlled. The staff that work on the voltage desk were chosen for this research because they have the most interactive and complex tasks to perform. A total of six voltage controllers were interviewed. Two extra staff members were included in the interviews in order to draw comparisons.

**In total, eight staff members were interviewed.**

These were:

- **Two Senior Advisors (SAs),** they are the most competent of the group;
- **Two Expert Voltage Controllers (EVCs),** with many years of experience;
- **Two Novice Voltage Controllers (NVCs),** they have been recently authorized to work on the voltage desk;
- **One Novice Female Controller (NFC),** not working with the voltage desk, she was selected in order to draw comparisons with the others; and
- **One Man Machine Interface Developer (MMID),** that works at the National Control Centre (NCC). He was included to identify any differences in mental processing between designers and expert users of MMIs.

## 2.1 STEPS THAT WERE FOLLOWED DURING THE INTERVIEW PROCESS

At this point it is important to mention that the controllers were not consciously aware of their mental strategies and visualizations prior to the interviews. Therefore the process used to reveal the strategies and visualizations has a number of " stages" which are:

- The preliminary discussions, served the purpose of bringing to the surface of the controllers' minds the context in which we would be working.
- The simulator sessions provided the opportunity to actually engage and use the mental skills to be elicited. It is important to note that the simulator sessions went a long way towards establishing the controllers in a real "working state" under contingency conditions. This is evident on the video recording as well as by the controllers' own admission, during the interviews. The presence of the video cameras also added to the intensity of the exercise.
- The formal interviews, which followed immediately after the simulator work, took the process deeper so that the elicitation could be completed. This stage required considerable time as the ground covered was unfamiliar to the controllers who had the view that there was "nothing there" to report. 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

and then ask them to notice and describe the content of their experience. A relaxed atmosphere was required for this work. In one instance, the controller interviewed was called away for about an hour. When he returned, he was able to identify his mental representations much more easily than at the beginning of the interview. During the beginning he had great difficulty talking about things that he didn't know existed. His observation was that during the time he was away he had the opportunity to ponder over the questions asked without pressure. In this way, he reported that he became aware of very vivid imagery and mental processes. These are recorded in the findings section, Appendix C.

**The formal interview process included the following steps:**

1. **Preliminary discussions** were conducted with the eight participants as well as with the person responsible for the network simulator. During these discussions the tasks that they perform during the normal course of their work were outlined and discussed. From the information that was obtained during the above discussions a simulator task was designed for the seven controllers. The person responsible for the simulator and me determined this task. The controllers were not informed of the type of task that they would be asked to perform.

2. The control task was then set up on the national grid simulator for the seven controllers to perform (the MMID was not included). This task consisted of a 400 kV line trip, followed by a second 400 kV line trip a few seconds later, in the same grid region. This double contingency would normally result in a voltage collapse in the area, if left unattended. The controllers were instructed to do all they can to ensure that the network recovered and that nominal voltage levels were maintained. These **simulator sessions** (about 15 min per person) were video recorded. The participants were asked to verbally describe what they were doing while working, in this way the verbal protocols were included in the video footage.

3. A **follow-up formal interview session**, taking many hours (a full day was used for each person interviewed), was conducted immediately after each simulator session. In this, the video footage just taken was played back to the controller so that he / she could view themselves working on the simulator and further describe what they were doing, as well as what they were thinking at the time (retrospective VPA). These retrospective verbal protocols were video recorded. The controllers enjoyed these follow up sessions and emphasised that they learned a great deal from watching themselves work.
   During this phase Metamodel questions as well as Sub-Modality questions were used to elicit the controllers' metal experience (under each of the categories listed in the modelling process).

By means of the above questions the internal factors, that play a role in the controller's mind, were elicited under the categories:

- Operating Strategies, and
- Mental Visualization during work.

The **MMID was interviewed** separately in his own office, using the same Metamodel and Sub-Modality questioning techniques used for the others. Instead of giving him a control task to perform however, he was video recorded doing what he normally does. He was then video recorded again describing his internal representations as he observed himself working. The rest of the interview was then carried out just like with the controllers.

4. After the stage in the interview where the mental control strategies and visualizations were elicited, a list of general questions, listed below, was presented to the eight participants. Most of these were formulated from the literature review, the rest were created after the initial interviews with the controllers to cover a broad spectrum of factors that may impact on their performance.

**NOTE: The participants' responses to all the questions that follow were recorded. However they will not be included in this dissertation as they fall outside the scope of the research questions. They are listed below in order to demonstrate that the interview process was very extensive. On average it took a full day with each participant.**

**The questions relating to maters outside the research questions were:**

- **What makes your work easier** (people, equipment, environment, conditions, prospects, requirements, internal factors, abilities, beliefs, values, identity, purpose, mission, other)?

- **What makes your work more difficult (**as above)?

- **What areas of your life have impact or play a significant role in your work at national control?**

- **What items, in order of priority, would have the most beneficial effect on your performance?**

Following these questions three lists of fifteen emotion bipoles, as obtained from Shalif [62] arranged with a seven-point scale for each bipole, were given to each participant. They were then asked to score the intensity, on each seven point bipole scale, that they experience for each of the fifteen emotions during three different scenarios:

- **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.**

From the above ratings emotional state signatures were obtained for the three scenarios.

**Following this, they were asked to describe and draw the image of a metaphor that they would use to represent the network.**

**The controllers were then asked to design a control room of their choice.**

**A list of questions that emerged from the literature review was included in the interview, these were:**

How adequately trained are you in the following fields:

- **POWER SYSTEM COMPONENTS**
  - Power Generation
  - Electrical Networks
  - Substations & Equipment
  - Protection & System Automation
  - Power Demand (Loads)
  - Enabling Technologies (SCADA / EDS)

- **OPERATION**
  - Normal Conditions
  - Emergency Conditions

- **CONTROL**
  - $f$-P Control
  - V-Q Control

- **OPTIMISATION**
  - Power Economics

- **QUALITY OF SUPPLY**
  - Power Quality

- **REGULATORY & INSTITUTIONAL ENVIRONMENT**
  - Operation under Competitive Conditions

**Do you as controllers get the information easily in your "head" from what is displayed?**

Following on the theme of the increase of demands made on Control Centres (CC), L Bainbridge (industrial psychologist) in an article titled "Study of Real-time Human Decision-making using a Plant Simulator" identifies a lack of knowledge concerning the thought processes of CC 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.

As the author very aptly puts it "…controllers do not want information on the control panel they want it in their heads".

The statement above was presented to the controllers and their comments were recorded.

**Is the existing set-up at national control such that it can deal with all the phenomena listed in Table A1., at appropriate time scales?**

In an article entitled "Stretching the Limits of Power System Analysis" L V Mitsche lists the power system phenomena that CCs 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 the simulation tools that can be used to address them, as follows.

**Table A1.** Power System Phenomena, available Power System Controls, and appropriate Simulation Tools.

| **Power System Phenomena** | **Power System Controls** | **Simulation Tools** |
|---|---|---|
| **Surges** ($10^{-4}$ to 0.1 s) | HVDC, SVC, GENERATION CONTROL | SURGE S/WARE |
| **Power Swings** (0.01 to 10 s) | PR. MOVER & GEN. CONTROL Low Frequency Control (LFC) | DYNAMIC SIMULATIONS |
| **Frequency Variations**(10 s to 1 hr) | PR. MOVER CONTROL, LFC, CONTROLLER ACTIONS | & POWER FLOW& OPT. P/FLOW |
| **Economics** (5 min to 1 day) | PR. MOVER CONTROL, LFC CONTROLLER ACTIONS | & SECURITY CONSTRAINED OPTIMIZATION |
| **Operations Planning**(1 hr | PR. MOVER | & UNIT COMMITMENT |

| | | |
|---|---|---|
| to over 1 year) | CONTROL, LFC, CONTROLLER ACTIONS, & SYSTEM REINFORCEMENT | & PRODUCTION SIMULATION |
| **Planning** (months to years) | SYSTEM REINFORCEMENT | & RELIABILITY |

The information above was presented to the controllers and their comments were recorded.

**Does the information presented to the controllers get classified under the categories listed below?**

- Pre-despatch;
- Dispatch; and
- Post-dispatch.

**To system states of:**

- Normal;
- Degraded; and
- Restorative.

**The time that it takes to process information is specified below. Are controllers aware of these categories, do they agree with the allocated time values and does the existing system comply with them?**

Visual momentum is a term used to indicate the rate and rhythm with which a controller's attention moves from one point of fixation to the next.

In this respect, the following are to be considered and the controllers' responses to be noted:

- Information "chunking" and the time intervals between chunks.
- Entry verification time (how long it takes for the computer system to verify that an operation has been accomplished).
- Response time during controller-system interaction.
- Response time to controller inputs.
- Response times to controller requests.
- Response time variability and its relation to system states (normal or not).
- Scan rates as well as controller response times.

**It has been shown, that controller response speed increases with stress levels up to a point where it abruptly drops to below acceptable**. This is a fundamental limitation of the whole process of power system control, as the controller is the one on who all the other systems converge in order for the network to function properly. The issue of stress is a great factor that should not be underestimated.

The significant aspects of the time responses of the control system are:

- The time for the control system to respond to controller action / requests.
- Consistency of time related aspects of control system operations.
- Control system conditions as they get translated into time responses.

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.

Are controllers aware of the time frames below and do these time frames represent the response times of the system that they use.

The following response times were highlighted as upper limit response times:

- 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 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.

These times further depend on the system's state of emergency and the controller's stress level. The idea is to not disrupt the controller's thought process. 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 minimise the disruptive effect.

**Do they agree with the following recommendations?**
**Are these implemented at national control?**

From the literature review a list of 13 recommendations follows. This would go a long way towards addressing a great number of shortcomings identified for control

centres in the USA. The response required from the ESKOM controllers would be: agree or disagree, and comments.

They are:

1) Develop and present more transformed data (from data to information).
2) Present this information in varying time domains as per system state and operating conditions.
3) It is to be accepted that controllers require information in a way that will aid them in restoring the system to its normal state.
4) The overabundance of raw data during degraded power system states is to be reduced.
5) The controller should be informed of significant changes and their consequences at a higher level of priority.
6) Dynamic methods of detection, utilization and display of power system abnormal operating states should be implemented in application software and in warning systems.
7) Overall integrity of system communications should be displayed to increase confidence in decision-making.
8) The priority of system state information provided should be based on the levels of power system states.
9) Post-dispatch functions (logs, reports etc.) should be automated.
10) Alarms should be dynamically prioritised and only displayed at stations where they are of value.
11) 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).
12) Predictive algorithms should be utilised for State Estimation, Power Flow, Contingency Analysis, and Preventive Actions.
13) Load shedding and similar operations should be automated based on system performance.

**The controllers were asked to comment on the aspects listed below within the control room environment.** The idea was to identify if these were adequately considered in the control room design.

- Anatomy
- Physiology
- Sensory Physiology
- Psychology

**Are the following aspects considered within the control room environment?**

- Condensing of large data sets.
- Functional relationships should be considered over spatial ones in plant modelling
- Grouping of information displays with relevant controls to reduce risk of incorrect operations.
- Arrange control interfaces according to operator instinctive reactions during emergency conditions rather than his / her cognitive reactions.
- Standardise displays and controls to avoid errors due to expectancy.
- Differentiate displays in various levels in terms of importance, function, and criticality.
- Minimise the controllers visual scan, reach and walking requirements.
- Arrange control areas according to medium (steam etc.) or energy flow.
- Ensure an integrated approach to the display of alarms and data.

**Which of the two scenarios listed below applies at national control:**

**Scenario 1.**

| **Power System Analysis Tool operations** | **Controller mental processing** |
|---|---|
| Collection of data.<br>Computation.<br>Presentation (**numerical**). | Recognise data items.<br>Build mental model.<br>Interpret the model (analysis).<br>High-level information extraction. |

**Scenario 2.**

| **Power System Analysis Tool operations** | **Controller's mental processing** |
|---|---|
| Collection of data.<br>Computation.<br>Presentation (**graphical**). | Analysis.<br>High-level information extraction. |

**At the end of the interview, the system representation methods listed below, were presented as computer displays alternative to current practice. They were then asked if they are aware of them, as well as if they would consider using them.**

**The following computer display techniques were presented for comment:**

**Data maps** (geographical map), the current 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 abovementioned 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.

**The following three keys to designing effective graphical representations were discussed, they are:**

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

The visualization strategies discussed essentially convey information about two key concepts.

- How the loss of one element affects the rest of the system, i.e. the **severity** of the loss of each element, and
- How each element of the power system is affected by the contingency set, i.e. the **vulnerability** of that element.

The controllers were asked to comment on them.

The current state of the art of the "Visualization of Power Systems" is presented in a Final Report generated by the Power Engineering Research Centre, in 2002, of the same title, compiled by T J Overbye [17]. Overall this report appears to present the most significant and up to date efforts in design and implementation of visualization tools available in the USA. Samples of the displays included in the above report were shown to the controllers on a computer monitor. They were then asked to comment on the merits and shortcomings of each display sample, as well as if they would prefer the displays shown to the ones they currently use.

This concluded the formal interview process. On average, about four and a half hours video material per was recorded per participant.

**EQUIPMENT USED**

The following equipment were used to conduct the research:

- One digital video camera.
- One Hi8 video camera.
- An Apple G4 computer.
- Video editing software.
- One analogue to digital video signal converter.
- One data projector.
- One PC with 21 in. monitor.
- One printer.
- Various consumables, video-tapes, etc.

# APPENDIX D

# FINDINGS FROM INTERVIEWS

**In this section, the findings from the interviews conducted with the controllers and the MMID are listed under the following headings:**

- **How they work on the simulator.** Here, observations of controller' physiology, equipment layout patterns, and usage during simulated contingency sessions are presented.
- **Control Strategies.** In this section what they look for (both externally and internally) and in what order during their voltage control work is presented.
- **Visualization.** In this section what they mentally visualize under normal voltage control and during contingency conditions is presented.

## 1. FINDINGS FROM THE WORK ON THE SIMULATOR

The equipment used in the simulator comprised of two TV monitors, two keyboards, one for performing switching operations (SW), and the other for selecting displays on the monitors (DISPL), and a mouse. This equipment was arranged as shown below.

## OBSERVATIONS FROM THE WORK DONE ON THE SIMULATOR.

### SAs

It was observed that the two SAs used both hands, one on the mouse and the other on the SW keyboard, to perform control functions (of the two, one is left handed). They remained relaxed and appeared confident sitting back on their chair. They used small hand and wrist movements in their work. Their head movements were also small. They seemed to maintain an overview of their environment, working fast and anticipating contingencies. The distance between their head and the monitors was maintained at over one meter.

### EVCs

The two EVCs also seemed calm. Their movements were slower than the two SAs; they both sat forward on their chair and seemed to peer into the monitors more fixedly (this may have cognitive implications of not considering the "big picture" as well as having a reactive rather than proactive attitude with an external locus of control). Of the two, only one used both hands to work. They both leaned on their elbows and supported their chin with their left hand when not using it. Their hand movements were large and thus took longer. Their head to monitor distance was about 0.8 m. Of the two the one was quite sensitive to the volume of the audible alarms.

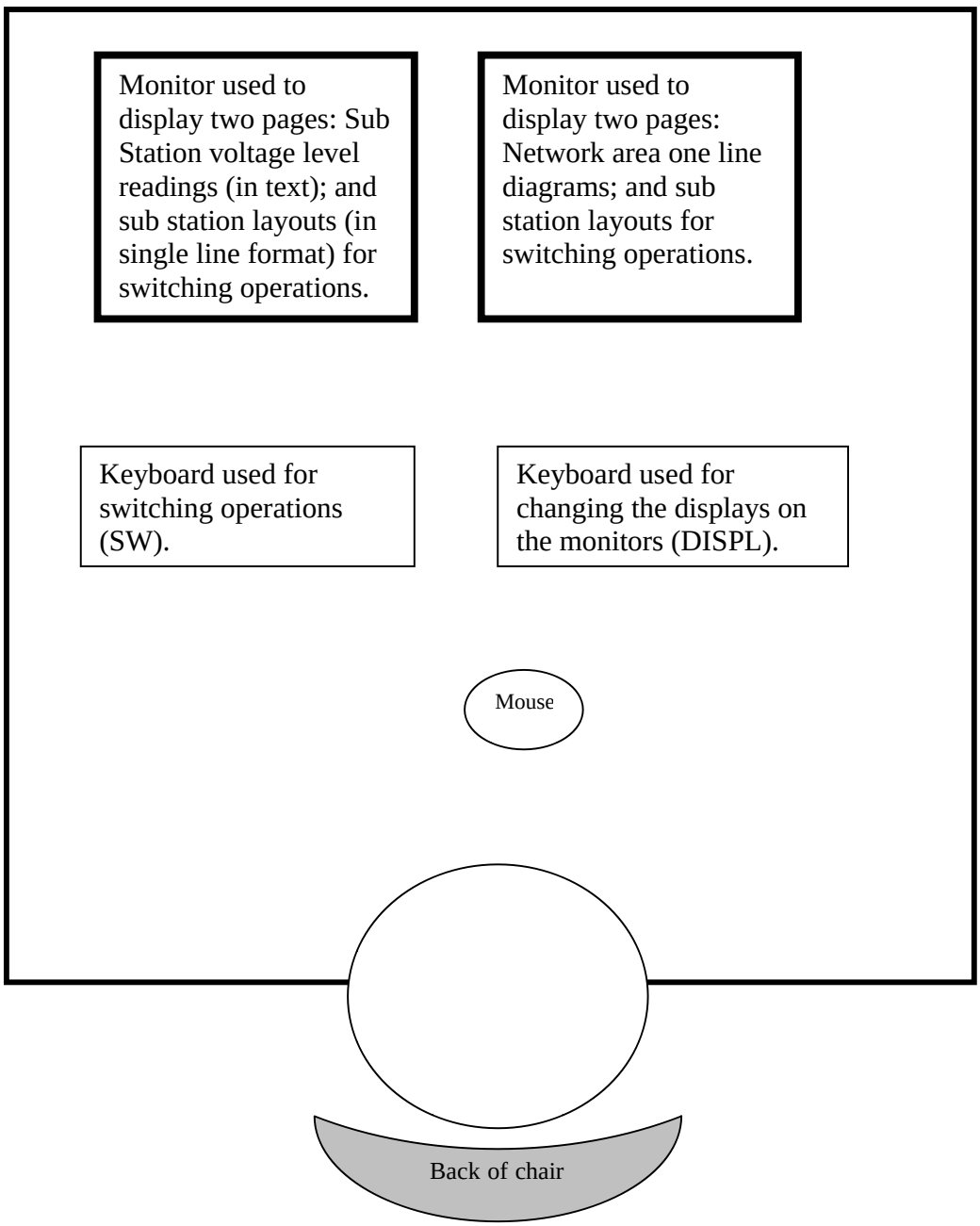



**Fig. C1.** Simulator Room Equipment Layout

## NVCs

The two NVCs used only one hand to work both the mouse and keyboard, with their left hand not used at all. They appeared stiffer and more abrupt in their movements, focussing on the monitors (peering into them with similar possible cognitive consequences as the two EVCs).
**Their movements were big and abrupt / fast. They seemed to experience and display strong emotions. Their head to monitor distance was about 1m to 0.8 for the one and 0.8 for the other.**

## NFC

The NFC was similar to the NVCs but was even more drawn in by the monitors, progressively moving her head closer. As the simulated contingency unfolded she seemed very worried. Her movements were big (both body and right arm); her left hand was folded behind her back and not used at all. Her head to monitor distance went from 0.7m to about 0.5m. She appeared sensitive to the sound level of audible alarms.

## MMID

The MMID did not use the simulator. Instead, he was video recorded at his normal work place. He works in an office in front of a monitor the same size as that of the controllers. The distance between his face and the monitor is about 0.4m.
His ability to see the information displayed is thus better than the controllers who at best get to about 0.7m to over 1m away. His work does not involve interacting with an ever-changing network; instead he is responsible for finding practical ways of converting data to information.

# 2. CONTROL STRATEGIES.

During the interview part of the research, the control strategies, i.e. what the participants look for and in what order, were identified. By reviewing the video material and extracting the relevant information a matrix that contains sixty observations or statements was created. In this matrix what the participants said during their interviews is listed on the vertical axis and the eight participants are placed on the horizontal axis. X marks were inserted where comments came from a particular participant.

**Table C1.** Controller response matrix, (X) indicates origin of comment.

| **Control strategy aspects and sequences, as identified in the interviews conducted with the eight participants.** | **SA1** | **SA2** | **EVC1** | **EVC2** | **NVV1** | **NVC2** | **NFC** | **MMID** |
|---|---|---|---|---|---|---|---|---|
| **SA1**<br>1) I do a "gap analysis" to see if voltages at busses are within the values that I want them to be. | **X** | **X** | **X** | **X** | **X** | **X** | | |
| 2) I have predetermined voltage ranges as reference for "gap analysis". These are self-created. They are: higher than nominal voltage levels for high load periods; and lower than nominal for low load periods, so as to have the bus voltages in the most advantageous level, for particular point on the load curve. | X | **X** | **X** | **X** | | | | |
| 3) I experience intense feelings to act or relax according to the value of the "gaps" between my references and the actual bus voltages. | X | **X** | | | **X** | **X** | | |
| 4) I prioritise grid regions and scan them as per level of priority. | **X** | **X** | **X** | **X** | **X** | **X** | | |
| 5) I am mindful of what time of day it is. | **X** | | | | | | | |
| 6) I note the active alarms on the control monitors at shift take-over time. | **X** | | | | | | | |
| 7) I visualize simple "box" type diagrams depicting specific areas of the grid when doing switching (working). | **X** | **X** | **X** | **X** | | | | |
| 8) By using such simple "box" type visualization I relate one grid area with another (I "step back" to see the big picture). | **X** | | | | | | | |
| 9) I consider the consequences of switching in one area on the other areas. | **X** | **X** | | | | | | |
| 10) I use the simple " box" block diagrams to obtain direction as to where and what to work on next. | **X** | | | | | | | |
| 11) Decisions are made within seconds under emergencies. | **X** | **X** | | | | **X** | **X** | |
| 12) I keep working until bus voltage values are as per my reference, so that I can sit back with a feeling of satisfaction. | **X** | **X** | | **X** | **X** | **X** | | |
| **SA2**<br>13) I create a mental template of upper and lower (+ and – 5%) voltage level limits. I use this template to scan the bus voltage display page. | **X** | **X** | | | | | | |
| 14) I divide the bus voltage display page in four sections. | | **X** | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 15) I don't read but "scan" the bus voltage values on the monitor page against my mental template. | | **X** | | | | | | |
| 16) I mentally drop information that I don't use. | | **X** | | | | | | |
| 17) When the bus voltage values are close to my limits I experience an "orange" alert feeling. | | **X** | | | | | | |
| 18) When the bus voltage values are out of the 5% limit I experience a " red alert" urgent feeling. | | **X** | | | | | | |
| 19) I start my work by checking the grid regions in sequence, W-Cape, Natal etc. | | **X** | **X** | **X** | **X** | **X** | | |
| 20) I use key reference voltages at specific busses so that I don't have to scan the whole bus voltage page. | **X** | **X** | **X** | **X** | | **X** | | |
| 21) I compare what I see on the monitors to the mental image in my mind of the key substations and voltage values. | **X** | **X** | **X** | **X** | | **X** | | |
| 22) I use my own pre-established operating strategies / sequences as per area of operation. | | **X** | **X** | | | **X** | **X** | |
| 23) These sequences are different depending on the time available to react to an emergency. | | **X** | | | | | | |
| 24) I have three categories of pre-determined operating sequences: normal; abnormal; and critical. | | **X** | | | | | | |
| 25) I experience three different feelings: normal, when long response time is available; abnormal, (pushing in my gut); and urgent (butterflies in my gut) as response times required get shorter. | | **X** | | | | | | |
| 26) When the "abnormal" or "urgent" feeling comes up I get pictures in my mind of what to do. | | **X** | **X** | | | | | |
| 27) I check my decisions with the shift manager if there is time. | | **X** | | | **X** | **X** | | |
| 28) I step back and see the big picture. | **X** | **X** | | | | | | |
| **EVC1**<br>29) I write down my switching operations before switching, except in emergencies. | **X** | **X** | **X** | **X** | **X** | **X** | | |
| 30) I select a switching point, read / verify the information about it, operate, wait to see that the operation happened, and then move on. | | | **X** | | | | | |
| 31) When there is a fault I ask what caused it. | | | **X** | | | | | |
| 32) "Experience" means it happened before. | | | **X** | | | **X** | | |
| 33) W/Cape is the most sensitive area. | **X** | **X** | **X** | **X** | **X** | **X** | | |
| 34) I am "too" calm. | | | **X** | | | | | |
| 35) I act from "experience" or do as I am told. | | | **X** | | | | | |
| 36) I know the consequences of load shedding at different busses. | | | **X** | | | | | |
| 37) "Serious faults sharpen you up into an alert state." | | | **X** | **X** | | | **X** | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **NVC1**<br>38) When there is a fault I have pictures in my mind of voltages going low. | | | | | **X** | | | |
| 39) When there are faults I see pictures of red alarms flashing in my mind. Sometimes I find that they are more in my mind than in actuality. | | | | | **X** | | | |
| 40) I imagine the consequences of a fault and some times feel that I'm loosing control. | | | | | **X** | | | |
| 41) If the time to respond gets shorter than a certain amount I start closing lines at random with out analysing. | | | | | **X** | | | |
| 42) When faults happen faster than one at a time I get a feeling that I don't have control of myself. | | | | | **X** | | | |
| 43) During contingencies I experience strong emotions, shaking of my body, hot burning anxiety in my gut and feelings of confusion in my head. I only become conscious of these after the event has passed. | | | | | **X** | | | |
| 44) Anxiety during contingencies results in confusion, which limits my information processing capability. | | | | | **X** | | | |
| 45) During contingencies I need others around me to feel that I am not alone and thus feel able to stay calm. | | | | | **X** | | **X** | |
| NVC2<br>46) I have detailed pictures of the network in my mind. | | | | | | **X** | | |
| 47) I like the adrenalin rush that goes with the emergencies. I prefer busy times. | | | | | | **X** | | |
| 48) I "blank out a bit" when double faults occur. | | | | | | **X** | | |
| 49) I always check with shift manager first. | | | | | **X** | **X** | **X** | |
| **NFC**<br>50) I think in terms of what I see on the monitors. | | | | | | **X** | **X** | |
| 51) I expect to have my instructions confirmed before I execute them. I must wait to be told to act in the role that I am in. | | | | | | | **X** | |
| 52) My work is not as urgent as that of the voltage desk. | | | | | | | **X** | **X** |
| 53) I love my work. | | | | | | | **X** | |
| **MMID**<br>54) I have / can create a complete 3D picture in my mind of what I work with. | | | | | | | | **X** |
| 55) It is dynamic (as in I can change it as I want), uncluttered and in very specific clear colours that have a harmonious relationship. | | | | | | | | **X** |
| 56) I visualize the network in voltage layers in the form of a pyramid. | | | | | | | | **X** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 57) Controllers get used to displays that are very difficult to interpret. | **X** | **X** | **X** | **X** | | | | **X** |
| 58) Controllers have high thresholds of emotional stress (thick skinned). | **X** | **X** | **X** | **X** | | | | **X** |
| 59) My work does not involve stress. | | | **X** | | | | | |
| 60) I get a lot of satisfaction from my work. | | | | | | | **X** | **X** |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

There is no special section for EVC2 as all his comments were available on the other sections (see Xs).

What follows is a summary of the information that emerged from the matrix.

The six voltage controllers are considered first, followed by the female controller, and the MMI developer.

**The following comments came from all the six voltage controllers** (two SAs, two EVCs and two NVCs):

1. I have a strategy to do a "gap" analysis to see if voltage levels are within predetermined values.
2. I prioritise regions and scan them as per level of priority.
3. I keep working until voltage values are as per the desirable reference.
4. I start working by checking regions from the western cape upwards.
5. I manually write down on paper what I intend to switch except under emergency conditions.
6. All six agree that the western cape is the most sensitive region.
7. I scan key reference voltage points in the different regions.
8. I divide the voltage display page in four regions and thus minimise the amount of scanning required to monitor the regions.
9. All six compare what they see on the monitors to mental images. However these images vary from group to group.
10. All six make decisions within seconds during emergencies. However these decisions are not always correct.
11. I use different control strategies depending on the region on which I work.

**The following comments came from both the two SAs and the two EVCs.**

1. I have predetermined voltage ranges as references for conducting a gap analysis. These ranges are self-created. For the one SA it is high voltage references for high load periods and low voltage references for low load periods. The other SA has a mental template that has a low and a high value

in it. He then uses his mental template to scan the voltage level information (in text form) on the monitors in front of him. What is interesting about this strategy is that he does not remember / register the actual voltage values that appear on the monitors if they fall within his template references.

2. I use simple block diagrams in my mind to isolate an area on which I work. This "rubber banding" is the most significant strategy step difference between the experienced and the inexperienced group. This will be discussed in detail in the following section under visualization.
3. They all compare what they see on the monitors with the above simplified block diagrams in their mind. This strategy gives them direction as to where to go next (big picture).
4. They consider the consequences of their operations on other areas in the network.
5. When there is a fault I ask what caused it.
6. Controllers get used to displays that are very difficult to interpret.
7. Controllers have high thresholds for stressful emotional states.

**The following comments come from the two SAs.**

1. I (mentally) "step back" and see the big picture regularly.
2. My control sequences vary, depending on the available time to respond to an emergency.
3. I experience intense feelings related to how big the difference is between my (mental) reference and the actual voltage value on the monitors.
4. I am mindful of what time of day it is.
5. I mentally drop information that I don't use.
6. When my voltage limits are approached I feel orange alarm feelings (pressure in my gut) when they are exceeded I feel red alarm (butterflies in my gut) feelings.
7. I have three categories of pre-determined operating sequences, normal, abnormal, and critical.
8. When an abnormal or urgent feeling comes up I get pictures in my mind of what to do.
9. I check with the shift manager if there is time.

**The following comments come from the one EVC.**

1. I select, read, operate, and wait to see that the operation happened before I move on.
2. Experience means it happened before.
3. I am too calm.
4. I act from experience or as I'm told.
5. I know the consequences of load shedding.
6. Serious faults sharpen me into an alert state.

**The following comments come from the NVCs.**

1. When there is a fault I see the voltages go low in my mind.
2. When there are faults I see pictures of red alarms flashing in my mind, often they are more than what I actually discover on the monitors.
3. I imagine the consequences of a fault and some times feel that I'm loosing control.
4. If the time to respond gets shorter that a certain amount I start closing lines at random without analysing.
5. When faults happen fast and more than one at a time I feel that I don't have control of myself.
6. I experience strong emotions, shaking, hot anxiety in my gut and feelings of confusion in my head, which limits my information processing capability. I only notice these after the event has passed.
7. I need others around me to feel that I'm not alone and able to stay calm (see [60] p389).
8. I have detailed pictures in my mind of the network.
9. I like the rush that goes with emergencies. I prefer busy times yet suffer from chronic back pain.
10. I 'blank out" a bit when double faults occur.
11. I always check with the shift manager first.

**The following comments come from the NFC.**

1. I think in terms of what I see on the monitors.
2. I expect to have my instructions confirmed before I execute them.
3. I must be told to act in the role that I am in.
4. My work is not as urgent as voltage control.
5. I get a lot of satisfaction from my work. I love my work.

**The following comments come from the MMID.**

1. I have / can create a complete 3D picture in my mind of what I work with. This picture is dynamic ("I can change it as I want"), Uncluttered and in very specific clear colours that have a harmonious relationship.
2. I visualize the network in layers of a pyramid.
3. Controllers get used to displays that are very difficult to interpret.
4. Controllers have very high thresholds of emotional stress.
5. My work does not involve stress.
6. I get a lot of satisfaction from my work.

## 3. NETWORK VISUALIZATION

This section represents a most significant part of this investigation. The information below shows what the individuals in the various groups do in their minds in order to visualize the information presented on the monitors. The visualization enables them to make decisions about how to maintain the network voltage levels within 5% of nominal. In this respect I was almost exclusively interested in identifying the visual aspects of their mental representations as it is well accepted that mental representations are varied and many of them are not available for conscious scrutiny. However the kinaesthetic component came across very strongly, as an inseparable dimension of their experience. Of particular importance is the fact that the SAs and the EVCs stressed the fact that they " feel" the state of the network. This is a very important part of their expertise. They said that if they have been away from the voltage desk for long periods (days or weeks), it takes them some time before they can work at their best levels of performance again. The same felt sense was reported to guide them to make quick decisions during contingencies, when there is no time to think and analyze the situation.
It is particularly significant to note that the visualizations described below are not at all similar to the metaphors that were used by the controllers to describe the network consciously (see Senge's ref. to Argyris [77]). The metaphors were general concepts like: " the network is like an aeroplane", or a " water distribution system" etc.

The following observations were noted:

**SA1:**

1. He had a mental page with voltage values that he used as a template against which he compared the actual voltage display page. When there were discrepancies he felt pressure in his chest, this prompted him to act and make corrections.
2. For analysis work he had a mental image of the whole network in front of him, first as a ball (+/- 20cm) then he opened it out flat in full colour, at arms length (+/- 4 $m^2$). He only looked at one Region / Area / Station at a time, as the whole was too big to see all at once.
3. For contingencies he used unlabeled blocks (the mental image had +/-7 parts) with lines in between them, white on grey background for determining what to do next and to identify the consequences of his actions.

**SA2:**

1. He had a small mental template with +/-5% voltage values in it (a small block) that he " ran" against the bus voltage values displayed on the computer monitor. He had divided the computer voltage-display page into quadrants. From scanning the voltage display page he gets either a normal, abnormal (close to 5%) or urgent feeling (over 5%).
2. When there was a fault, he mentally saw the area involved with just a few lines and no labels (the mental image has +/- 7 parts) together with a flashing red block in it that told him there is trouble.
3. Then he had mental " cards" of instructions with lists of things that he must do. These cards are white (for normal condition switching), yellow / orange (for abnormal) and flashing orange (for urgent). The amount of information (procedural steps to correct problems) on them got less and less as the condition went from normal to urgent. He had a proactive approach and mentally discarded useless information. He cross checks his decisions with the shift manager to get perspective (big picture) when he can.
4. For network analysis under non-urgent conditions he used 3D simple mental pictures in colour, to work out consequences of actions. These are quite different to the ones that appear in his mind during contingencies.

**EVC1:**

1. He watched the voltage page and if there was a colour change on one of the numerical voltage values or if an audible alarm went off, he knew that there was a contingency. Then he asked what caused it. He also had simplified one-line mental diagrams of main sub stations that helped him to work out where to operate.
2. He worked from memory of past similar events when deciding what to do; otherwise he requires instruction from a senior person.
3. He used a simple mental image block with lines (the mental image had +/- 3 parts), to decide what to do. This mental diagram gets sharper with more contrast when there is trouble, this helps to focus his attention and increase the speed of his responses.

**EVC2:**

1. He scanned the voltage display page using key points and decided what needed attention (proactive).
2. During the contingencies he saw a "blob" representing the affected area with just the main lines shown (the mental image had +/- 3 parts). This switched on like a light while he worked and disappeared when the emergency was over.

3. He distinguished between normal and emergency network states. By mentally seeing closed breakers and MW values in his diagram he knew that things had returned to normal. In other words the mental images contained more information when things returned to normal.

**NVC1:**

1. During the double contingency he saw red alarms flashing in his mind (more than the actual number of alarms on the monitor) and got an out of control feeling.
2. He then saw mental images of what the substations look like physically start to fly past in a blur. He had difficulty finding use for these pictures. He then said that he was looking for a picture that would tell him what to do. He did not find such a picture so he could not decide what to do. This lead to anxiety and confusion.
3. He said that he then needs some one senior around him, for support, in order to think clearly.

**NVC2:**

1. He had mental pictures as well as an operating strategy for each region. His mental depiction of the network under normal conditions was very elaborate. This technical, one line drawing, image was similar with that of SA1 with whom he gets along very well.
2. During the double contingency he got fixated on the image of a capacitor bank and could not zoom out in his mind, to see the big picture, and thus know where to go next.
3. He was proud of his ability to have a very comprehensive image of the network in his mind but did not know how to navigate that image (unlike SA1). This led him to panic and freeze.

**NFC:**

1. She thought in terms of what she saw in front of her on the monitors. Her work does not require fast analysis or elaborate mental imagery like the voltage control staff.
2. When she saw the lines trip she thought that the person working on voltage control would have problems and felt alert.
3. She requires confirmation of her operations by a senior person.

**MMID:**

1. He does not deal with contingencies at all. His job involves no stress or time constraints. He works with a five to ten year horizon.

2. His mental images were sparse, clean, limited in variety, with colour coordination and visually aesthetic.
3. His criteria for good images are: Colour quality, and neatness.
4. He could, at will, create 3D, complex images (made up of +/- 9 parts) and metaphors, which he could manipulate with ease in mental space.
5. He was the most visual of the eight participants.

The above findings have been summarised in Appendix D, the summary is followed by recommendations for improvements and future research.

# APPENDIX E

# CONCLUSIONS, RECOMMENDATIONS, FUTURE RESEARCH

# 1. CONCLUSIONS

It appears that experienced controllers work by simplifying the information that they receive from the computer monitors by "rubber banding" (mentally focus on and isolate) the affected area. They mentally represent the key elements of that area with about five to seven (see Pinker [60]) parts of information. This allows them to deal with variety, complexity, and new events on the dynamic network by focussing on the perceived essentials. This is necessary, because the information presented on the monitors is far too extensive to absorb at once (the 7+/- 2 limit [56 & 60]). This is particularly true during contingencies where the simultaneously displayed alarms can run into thousands. These simplified mental diagrams assist them in deciding on what action to take and what will be the consequences of their actions within the affected area as well as the areas around it. The best among them do all of this proactively by drawing on memories and by visualizing new scenarios.

It seems that the new controllers are not aware of these "internal" cognitive steps, in particular the ability to zoom out mentally to get direction from seeing the big picture. They are now aware of the absence of this ability.

On the surface the MMID's strategies are in keeping with the controllers' requirements. However his images (also neat and simple) do not match those that they use. To this extent they are not keen to accept them because they don't fit in with what they have "programmed" in their minds. This may be part of what creates the perception that controllers are opposed to new things and change. On their side they say that changes "feel wrong" and that it takes time to get used to them. They experience this as stress, because of the potential consequences that may take place during the transition period, for which they will be held responsible.

The hidden competencies that are the very foundation of expertise in the control room have, until now, remained vague and invisible. This served to perpetuate the perception, in some minds, that the controllers' job is of a lower grade than that of system engineers. This view is totally incorrect, as their skill lies in being able to mentally integrate the entire network, during long periods of calm followed by contingencies, which are rare and demand instant responses, which may have grave consequences.

If the original list of difficulties that were identified during the first series of discussions with senior management at NCC is examined, it can be shown that most of the difficulties have been addressed:

**1)** It is a very real necessity for the national control staff to be able to **teach** their **skills to one another.**

**The transfer of higher order skills can now be achieved because the content as well as the structure of the mental models and strategies of the experts have been shown to exist.** Further work can be done to train the experts (at least those who are willing) in how to assist the novices.

2) It is also necessary to remove, or considerably **reduce, the uncertainty from competence transference.**

**As the experts and novices become aware of what they do and don't do in their minds the uncertainty in competence transfer is reduced.**

3) Knowledge transfer should take place in such a way that **"depth"** is achieved.
**Depth**: Correct real-time decisions, as a result of the new controllers' ability to put theory into practice in a short time.

**The above definition of depth has now been put into perspective. We now know what the inner skills are which make it possible to put theory into practice.**

4) There needs to be a **trainer's perspective** instilled in the NCC staff members, particularly those more experienced.

**This trainer's perspective is now something tangible, and therefore achievable, because the experts now have conscious access to their expertise.**

5) It is necessary to **capture the knowledge in the heads of experts so that it can be transferred.**

**All the findings address this point.**

6) **The wall display (in the front of the new control room) of the transmission network has been changed** from horizontal (old control room) to vertical. The new display has an upward turn in the grid layout that depicts the Western Cape region in a way that does not match geographical reality. More importantly however, it does not match the way that the network is depicted on the desktop monitors that the controllers use.

**This point has been addressed. The internal mental diagrams of the controllers have been shown to be different from what is displayed on the NCC wall. The controllers have mental diagrams similar to those on their monitors. As a result, there is a mismatch between what they**

**perceive in their minds during emergencies and what is presented on the wall display.**

7) More information is required to **determine** what the controllers' **views are about the new (circular) NCC** orientation as opposed to the old (rectangular) orientation.

**The controllers' views on this mater were that the new circular orientation was fine. Some recommendations that were made for improvements have been recorded elsewhere as this topic falls outside the research objectives.**
The controllers did however say that they did not "like" the wall display. The research findings show why they don't, as it does not match their internal representations or the network representation on the computer monitors which they use to work from.

8) Various, multi-layered configurations of network information representation are been proposed for implementation. **The relevance and desirability of** these proposed **computer representations need to be determined**.

**The proposed MMI display formats can now be compared for relevance with the existing mental models of the controllers. The controllers' mental models can be reviewed and changed as they have been shown to exist in content and structure. This applies to the experts (mental models to be modified) as well as the novices (mental models to be upgraded). The novices will most probably have less difficulty in adopting the new displays.**

9) There is evidence that **some** of the **procedures** in current practice have **not been instated with engineering principles in mind** (reactive power flow control sequences).

**This research did not address this problem.**

10) A **pilot training program**, which has been created for Network Controllers within the NCC, **needs follow up.** This is in order to determine if it meets all the requirements of the people that it is aimed at.

**The above program can now include cognitive training modules to address the metal skills aspect of expertise transference.**

11) A number of concerns have been raised about the controllers' **reluctance to accept proposed computer representations** of the network and its stratification.

**The controller's reluctance to accept "new" display formats is no longer a vague area of disagreement. As the controllers mental models are understood, by all concerned, intelligent decisions for flexibility on both sides becomes possible.**

Finally it is clear that, a greater understanding has been reached with respect to how the experts and novices at the ESKOM NCC process information in their minds. This directly addresses the research questions. We can generalize this result further, to say that in any other control room environment the revealing of the content and structure of expert and novice mental models can only enhance the efforts for the transfer of higher order skills. This accelerated skills transfer methodology can then be adapted to any environment, in South Africa or elsewhere, and at all levels of corporate structure.

## 2. RECOMMENDATIONS

### 2.1 Recommendations from the simulator work observations.

It is necessary to note, that even though the video recordings of the controllers at work took place in the simulator room, any recommendations made for improvements should be such as to improve their working conditions in the actual control room, where they normally work. In this respect the descriptions of the control room environment in Appendix B should be borne in mind.
**The controllers have to look at two screens (they toggle from screen to screen) of information on each monitor (they use two monitors, plus other equipment in front and around them). Their work conditions vary between long hours of inactivity, followed by moderate activity at load pick up and drop off times, and short bursts of "panic" when contingencies take place (very seldom). They work twelve hour shifts.**

After reviewing the simulator work video-recordings; observing the controllers at work in the control room itself (on separate occasions); and having discussions with them, the following recommendations are put forth:

1) **Training for two-hand operation of the keyboards and the mouse should be encouraged,** for reasons of speed and whole brain function.

2) The implications of head distance from the monitors should be investigated further (considering the input from ophthalmologists and ergonomics experts). **The participants should consider alternatives, with respect to**

**computer monitor position, height, distance, tilt, and colours used for the displays.**

3) The retrieval of information, obtained from the monitors by **intensely gazing into the screens, should be balanced by the accessing of the controllers' internal representations**. This may facilitate anticipation of events and a proactive operating style. Further video recordings of simulator work, as well as work in the control room, could be played back to the controllers in order for them to learn from self observation and expert reviews.

4) **Shifts (comprising of about five members) should train together in the simulator,** instead of staff working one at a time. These sessions should also be video recorded for review, in order to reveal group dynamics.

5) **More screens could be made available to display information as per individual controller preferences.**

6) **Audible alarms could be made more varied in tone** to distinguish between different types. Their sound level should be adjustable. At present the different audible alarms sound very similar to each other.

7) **The layout of the workstations should be tailored to individual preferences** in order to facilitate reaction speed and instinctive movement patterns.

8) The size of the font used for identifying the name of a substation, followed by a feeder name and a power line number is quite small (particularly if you sit far from the monitors as some controllers do). The placement of these words on the monitor is at the top left hand corner of the screen. The schematic one-line diagrams with the circuit breaker symbols etc. on them that are used for switching operations are displayed lower down and to the centre of the screen. The result is that controllers have to gaze up and down the monitor screen instead of having the words and the symbols together. This should be addressed, as it is one of the main causes of operating errors, by **making the fonts larger and placing the written information on the schematics.**
The MMID sits at about 40 cm away from the screen when he designs the displays, whereas the controllers sit more than 80 cm away, or even up to 1.2 m away.

9) **Chairs that fit individual controllers should be obtained.** This is very significant as the controllers vary greatly in size, shape, and gender. Each controller should have access to his or her own chair as they work twelve-hour shifts.

10) **More opportunities should be created for video recorded simulator sessions.** These should be played back to the controllers in order for them to learn by observing their own behaviours working individually and as a member of a shift. This last recommendation is of particular significance as it will increase self and group interaction awareness. During the review of such sessions expert controllers can share their cognitive skills as they become aware of their existence (following the findings of this research).

**2.2 Observations and recommendations from the review of the working strategies and visualization sections.**

1) From reviewing the findings section (Appendix C), it is evident that some practices are common to all controllers. The passing on of good practices however, is not done in a formal way. Individuals pick up what they can from their work with colleagues.
   Best practices should be identified and collated **so that novices coming into the system can adopt what suits them from various options. (Difficulties 1-5)**

2) There is evidence that **when an expert controller and a novice get along well** the transfer of skill is accelerated. This was determined from the interviews of SA1 and NVC 2. One of the main reasons people get along well with each other is that **their internal representations match**.
   This fact should be utilized when allocating novices to experts **for training**.
   This recommendation was particularly emphasised by the NFC based on her personal experience.

3) A number of **cognitive training interventions** (no cognitive training is taking place at present) **can be introduced** to address all the differences revealed (in strategy as well as visualization) between the controllers. At present training is regarded as the passing on of information and procedures, the inner mental skills being ignored, as no one was aware of them.

4) The **elicitation and formalization of the mental models and cognitive skills of the experts** could be one of the prerequisites for promotion, before they move on to a higher post within ESKOM. The advantage of this would be that the person taking over a job would have more than just information from their predecessor. This could be done with all staff upgrading. In this respect it is very important to recognize that each person has his or her own modality (visual, kinaesthetic, etc.) and other preferences. This means that formalized expertise models (in their entirety or in parts) will not be suited to all recipients, however the availability of such models will facilitate a different order of learning.

5) **Computer display designs can be designed in such a way as to take into account the mental requirements of the end users**. The simulator can be used to tailor such designs. In this respect there needs to be a balance between variety, due to individual preferences, and uniformity so that more than one person can work on the same equipment.

6) **Investigators of operating errors should consider the fact that actions originate in the minds of controllers.** Their mental "behaviours" can now be noted and suitable training designed to improve them. Ergonomic changes, to address cognitive shortcomings (Perky effect [60]), should also be introduced.

7) As can be seen from the two NVC interviews they have different cognitive problems to contend with. **A training program that progressively instils in the novices' minds the required cognitive skills could be formulated** to deal with the full range of cognitive skill requirements. This methodical transfer of the cognitive skills that have been elicited from the experts would go a long way to accelerate the training process. This may also reduce tensions, stemming from expectations, as the novices will have something concrete to aim for and will not be told to "wait" in order to obtain "experience".

8) **A new vocabulary can be created within the NCC**, so that all concerned can talk about their mental models, mental strategies, and visualizations. The creation, during this research, of the term mentally "rubber-banding" a contingency area, is an example of this. In this way awareness can be raised with respect to what "expertise" consists of in peoples minds, so that novices can consciously address their cognitive shortcomings.

9) The work done by the controllers is regarded, by some, to be simplistic. The mapping of the control strategies and mental models, as revealed by this research, will go a long way to show that **the controllers' real expertise is cognitive. This could be acknowledged through their performance appraisals,** in order to encourage others to develop such cognitive expertise.

10) In the case where **equipment upgrading** takes place (this is normally met with resistance), the **process can be made easier**. This will be because the mismatches between the current mental models (that were appropriate for the old equipment), and the new equipment will be seen for what they are. This should reduce the frustrations that stem from the feeling of something being wrong, or out of place, without being able to talk about it. It should be a lot easier to say that "the new monitor layout does not match my mental image", than to feel that it is wrong with out knowing why, and blaming some one else. The controllers stated, that when changes are implemented it is they

who have to adapt by rearranging their mental models. They experience anxiety because of this, as they will be held accountable for wrong operations. The example they gave, was that of driving a manual motorcar and then having to change to an automatic. This problem was further exacerbated because they were not aware of their own mental models. It would help therefore if they played a part in the design of the appearance of the new interfaces.

## 3. FUTURE RESEARCH

Emotional states play a major role in the control room environment. Equally critical are the relationships between the various members of a shift. These aspects of control room life will form the theme of another paper stemming from the current investigation.

It is incorrect to speak in terms of "controllers" as if they stand apart from the network and control it. This is far from the truth. The experienced controllers regard themselves as part of the network and report to know how it "feels" (this forms part of their expertise). **It is far closer to the truth to state that the network, the MMIs, the individual controller as well as every member of a shift and NCC management, even the controllers' family members all form a system.** This system has parts which affect each other with varying time constants and multiple layers of physical, mental, emotional, and technical interactions. This systemic view warrants further research, as we move towards more complex scenarios and larger networks (see [60] p392/3).It is my opinion that this should be considered, if not before, at least together with MMI designs from vendors that present their systems for controllers to "fit into".
MMI systems can then be engineered for greater levels of integration with the humans that use them.

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