Levels of Abstraction in Human Supervisory Control Teams

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This paper reports a study into the Levels of Abstraction Hierarchy (LOAH) in two energy distribution teams. The original proposition for the LOAH was that it depicted five levels of system representation, working from functional purpose through to physical form to determine causes of a malfunction, or from physical form to functional purpose to determine the purpose of system function. The LOAH has been widely used throughout human supervisory control research to explain individual behaviour. The focus of this research is on the application the LOAH to human supervisory control teams in semi-automated 'intelligent' systems. A series of interviews were conducted in two energy distribution companies. The results of the study suggest that people in the teams are predominately operating at different levels of system representation, depending upon their role. Managerial personnel work at functional purpose and abstract function levels whereas operational personnel work at physical function and physical form levels. It is argued that both types of personnel are part of the wider distributed problem solving system, which includes both people and technology.

KEYWORDS: Levels of Abstraction Hierarchy, Teams, Human Supervisory Control

Introduction

The research literature has put forward the Levels of Abstraction Hierarchy (LOAH) as a description of five different levels of system representation (Rasmussen, 1983; 1986). Studies have shown that these levels can be used to represent the decision space which is utilised by individuals in performing aspects of their task, shifting between the levels where appropriate (Vicente, 1999). The most persuasive arguments have been made by knowledge theorists (see Goodstein et. al., 1988) and empirical researchers (see Vicente, 1997; 1999). Vicente, in particular, has demonstrated how experimental participants are able to perform process control tasks more effectively if they are presented with both functional and physical information about the system. This represents both end of the decision spectrum. Rasmussen has argued that this is because people need to work 'top-down' when seeking the purpose of functional requirements and 'bottom-up' when seeking causes of system problems.

Many of the theoretical concepts in process control emanated from Rasmussen's work throughout the eighties (Rasmussen, 1983; 1986) and contributed towards recognising the human supervisory controller as a *'self organising component in a dynamic environment'* (p, 23, Sanderson & Harwood, 1988). Rasmussen's initial Skills Rule and Knowledge (SRK) classification was developed to assist system designers in better understanding human variability. Rasmussen intended to assist designers in building better interfaces, concluding that if system representation were more compatible with the operator's mental processes, there was greater likelihood of reducing human error and improving overall system performance (Goodstein, Andersen & Olsen, 1988). The approach has already been used to examine the roles of members of a nuclear power plant control team during different phases of operation (Gualtieri et al, 2000) and the respective roles of surgeon's and anaesthetist's in medicine (Hajdukiewicz et al, 2001). This research seeks to extend the analysis to energy distribution teams.

Therefore the main aims of the study reported here were to:-

- Briefly review human supervisory control research
- Conduct interviews with control room staff in two energy distribution centres in the UK
- Analyse the interview data using the LOAH classification
- Look for general trends in the classification data and draw conclusions for team work

The Levels of Abstraction Hierarchy

The purpose of this study was to examine Rasmussen's (1986) theoretical model (i.e. the Levels of Abstraction Hierarchy (LOAH)) in energy distribution control centres. The hierarchical representation characterizes the different levels of system representation from a concrete physical appearance of any system component to its overall, functional, purpose. As the LOAH forms the basis of the main study which is to investigate performance measures of engineers according to the system interface level represented, it was considered appropriate to carry out a study to investigate how control engineers currently think according to Rasmussen's framework. Furthermore, the LOAH was developed as a conceptual framework and to date has not been validated in an applied area of Human Supervisory Control; this study was therefore seen as a novel domain to examine the LOAH model.

The abstraction hierarchy was developed through a series of studies in trouble shooting (Rasmussen, 1986). Through extensive evaluation of the way in which people solved technical problems, Rasmussen noted that there were distinct levels for reasoning and thinking about a process. These levels differed in terms of their distance from the physical form of the plant and the overall system purpose. Rasmussen argued that the LOAH characterised the problem space of the decision maker. The hierarchical system has enabled researchers to think about the internal, cognitive processes of control room operators. Much of the earlier work was undertaken in the nuclear industry at the Riso National Laboratory where Rasmussen's work was set up specifically to conduct research into the Human Factors issues related to the control of nuclear power.

The LOAH hierarchy is divided into five distinct categories: from most concrete level (i.e. physical form) to the most abstract level (functional purpose). The definition of the categories are as follows:

<u>Functional purpose:</u> - The overall meaning of the system and its purpose in the world, e.g. system goals at a high level .

<u>Abstract function:</u> - General and symbolic level of the system, e.g. descriptions in mass or energy terms to convey flow through the system.

Generalised function: - Generalised processes of the system that reflects behavioural structure, e.g. diagram of information flow and feedback loops.

Physical function:- specific processes related to sets of interacting components, e.g. specific sub-systems, such as electrical or mechanical.

Physical form: - Static, spatial, description of specific objects in the system in purely physical terms, e.g. a picture or mimic of the components.

It was anticipated that the findings would support the LOAH model as a way of conceptualising the activities in control rooms. It is accepted that the original impetus for the development of the model was based on understanding troubleshooting behaviour, but subsequent research has used it as a general description for understanding the operators' behaviours in control rooms. Laboratory research has supported the model (Vicente, 1995), but there is a definite need to revisit the control room, to check the assertions for the LOAH model.

Human Supervisory Control

Human supervisory control environments (such as power stations, chemical plants, advanced manufacturing plants, and energy distribution centres) are examples of complex semi-automated 'intelligent' systems. Technological progress over the past fifty years has led to dramatic changes in the nature of working practices and behaviours in these systems (Kragt, 1992). Kragt describes the change proceeding through three evolutionary stages. The first evolution was from a world of isolated manual local control, where operators were physically responsible for controlling a small part of the whole process and had more sensory participation with objects of the plant, to pneumatics with set points and feedback loops. Pneumatics has enabled a greater number of parts to be supervised by fewer people. The second evolution, with the implementation of electrical transmitters, saw the centralisation of controls and displays into a single control room, where a small team of operators controlled more integrated parts of the plant units. Since the 1960's with the growth in computing and information technology, human supervisory control has progressed through its third evolution to the complex operation it is today. Through higher level information, automation and multi-user System Control And Data Acquisition (SCADA) systems, operators now have fingertip control of whole plants through a number of computer-based windows on the process. This latest evolutions has led to further reductions in personnel and increased remoteness from the physical system being operated and managed (Stanton & Ashleigh, 2000).

The role of the human operator has changed as a consequence of these technological developments, from overt physical effort to covert mental manipulations (Hollnagel, 1993). Many of the activities surrounding the control process do not appear to involve many physical control actions. Umbers, (1979), cited in Baber (1991) from his research of coal-fired power stations, estimated that control actions only occurred 0.7 times per hour; arguing that human supervisory control was largely a cognitive task requiring little physical action. This requires further research into understanding the way the human operator perceives, decides and acts. Although more information is available due to more sensors, and generally increased computing power, this has led to greater cognitive workload (Wilson & Rajan, 1995).

Researchers have developed cognitive models of human supervisory control that could help explain these profound shifts in human operator behaviour. Research paradigms can broadly be separated into three stages. During the early seventies, research was initially interested in individual cognitive control of human operators (Edward & Lees, 1974; Rasmussen, 1974). The impetus then shifted from concentrating on the individual operator to group structure behaviour and performance in the eighties, (e.g. Stammers & Hallam, 1985; Foushee & Helmreich, 1988). More recently the focus has been more towards an ecological approach of team work with a given context (Paris, Salas & Cannon-Bowers, 2000).

In this tradition, it was decided to interview people at their control room as a means of examining which levels of system representation people found most useful when describing their work. As stated earlier, it was anticipated that the LOAH framework would provide a useful taxonomy for classifying the interview data. This could then be used to understand the differences in system representation that people use when thinking about their work. If peoples roles determined the level of system representation they used, this might have implications for the way in which teams work and the way in which information about the system should be represented to them.

Methodology

Control engineers were interviewed at their place of work. It would hope that this would provide all the natural cues about their. Interviews were carried out on an individual basis. Engineers were asked to talk about activities they carried out and the way they made decisions. Open-ended questioning techniques were used to encourage participants to talk about the way they thought about each function they did throughout a typical shift pattern. Thus the structure of their working day was used as the structure for the interview. All interviews were of thirty minutes duration and were audio taped with the participants' consent.

The audio data were transcribed later and each statement was classified into one of the five LOAH categories (as described later in this section).

Participants

A sample population from each role was taken from two energy distribution companies in the UK: company A was an electrical energy distribution company and company B was a gas energy distribution company. Permission for access into the control rooms was granted. Each team had a team briefing and handout about the project before the control engineers were asked to be voluntary participants.

At Company A, each member of the team performed the roles as outlined in table one.

Table 1. Roles of the electrical energy distribution team at company A.

Role of personnel	**Overview of tasks**
Power System Manager (PSM)	Overview of power system Overall team management Liaison with the EME, SSE and TME Sanction of outages Policy compliance co-ordination
Energy Management Engineer (EME)	Direct real-time balancing Revision of operating plan Operational balancing when required Liaison with SSE and TME

National Dispatch Engineer (NDE)	Direct minute-by-minute operation and balance generation to meet demand and maintain frequency within limits Instruct pump storage plant and balancing mechanism units Issue programmes to GDE through dispatch systems
Generation Dispatch Engineer (GDE)	Instruct the balancing mechanism units output to follow the operating plans issued by the NDE Monitor the balancing mechanism units performance and prompt when necessary Ensure the balancing mechanism units operation meets system constraint requirements Assist NDE in frequency control
Transmission Management Engineer (TME)	Monitor the power system Sanction the release of outages Fault management and direction Liaison with EME and NDE
Transmission Dispatch Engineer (TDE)	Maintain power system security and quality of supply Reconfigure the system as necessary Switch out equipment for outages Liaison with safety co-coordinators, generators and other network operators
Assistant Dispatch Engineer (ADE)	Assists the TDE in tasks noted above
System Strategy Engineer (SSE)	Direct operation policy Check demand estimate Confirmation of trading process Sanction issue of operational programmes Liaison with EME and TME
Reactive Management Engineer (RME)	Accepts preliminary plans from the RE Re-evaluates the plan in line with changes Confirms the plan is viable Updates dispatch systems from plans Provides final operating plan to EME

	Sets system voltage profile
Rescheduling Engineer (RE)	Prepare the day ahead plans Modify plans in dispatch systems Provide preliminary operating plans to the RME Instructs and monitors warming balancing mechanism units to minimize costs Maintain contingency plant levels
Clerks	Provide administrative support to the control room Estimates demand using computer models Conducts end-of-day trading checks Monitors costs

Within company A, three sub-teams were present: the team leaders sub-team (PSM, EME, SSE and TME), the management sub-team (EME, NDE, and GDE), and the strategy sub-team (SSE, RME, and RE).

At Company B, each member of the team performed the roles as outlined in table two.

Table 2. Roles of the gas energy distribution team at company B.

Role of personnel	**Overview of tasks**
Grid Operations Controller (GOC)	Overview of system Overall team management Sanction of outages Policy compliance co-ordination Safe, secure and economic transmission
Grid Operations Engineer - strategy (GOE-S)	Overview of strategy System integrity Team development Emergency procedures Forecasting demand Control room administration Shift handover
Grid Operations Engineer - operations	Overview of operations Monitor system

(GOE-O)	Control system Contact other parties Maintenance work

It was stipulated that all participants should be experts (e.g. having had at least two years experience in their current role). The differences in the structure of the teams and their roles was due to inherent differences in the energy distribution companies, one dealing with electrical energy distribution and the other dealing with gas energy distribution.

Materials

A portable tape recorder was used in order to record all discussions with participants. A set of semi-structured interview questions were developed as a general guide for the interview. An introduction sheet was also used to remind participants of what the study was about and to collect biographical details.

Procedure

In order to gain full support and participation of this Knowledge Elicitation study, the interviewer initially attended team meetings for each individual team across the two companies. A brief synopsis of the project was given in a presentation and the current study explained in full. A handout stipulating what was required was given to each member of the control room. The study therefore had to be carried out over a period of eight to ten weeks in order to fit in with shift workers' rotations and to include a sample of every team.

The interviewer spent approximately thirty minutes with each participant whilst in his/her working situation on shift. All interviews were taped. Although a more intrusive method, it was considered that this would provide greater contextual data and examples of decision making processes could be easily illustrated if necessary. The study began with the interviewer asking specific questions from the structured interview sheet, followed by focused discussions about how the participant saw their role, what it involved, and what decision making processes they went through during their shift in each role. Open question techniques were used to clarify understanding and to probe further into a specific topic if necessary.

Analysis

The data was analysed by categorising each theme of discussion into the five different areas of the Abstraction Hierarchy. Agreement of themes was agreed by subject matter with experts from both companies. A frequency count was taken of each theme and categorised into each level of abstraction hierarchy. In order to gain inter-rater reliability, an expert from the domain was asked to listen to a sample of tape and to categorise the number of frequencies in each abstraction level. The categorization scheme is outlined in table three.

Table 3. Abstraction hierarchy categorization scheme.

Abstraction Level	Company A Electric energy distribution	Company B Gas energy distribution
Functional Purpose (FP: level 5)	Safe, secure and economic transmission Commercial strategy Setting policy Risk Assessment	Safe, secure and economic transmission Commercial strategy Setting policy Risk Assessment
Abstract Function (AF: level 4)	Stable voltage and frequency Operating with loading limits Monitoring operating margins	Operating within Network Code Optimising operation of system Anticipating problems
Generalised Function (GF: level 3)	Management of operating margins Demand prediction Optimising responses Management of standing reserve Planned and unplanned outages Constraint management	Managing demand prediction Management of system state Management of interruptions# Management of storage Maintenance management Alarm management
Physical Function (PF: level 2)	Target error display Force estimates Reserve spreadsheet Generator update Management of outages Management of alarms lists Planning switching operations	Managing supply and demand profiles Reviewing operational summary Managing stock program Reviewing forecasting models Managing alarm lists Managing site logs

Physical Form (P: level 1)	Conducting generation dispatch instructions Conducting transmission dispatch instructions Reporting alarms Logging faults Receiving incoming information	Recalculating demand profile Changing set points Changing stock levels Logging maintenance issues Reporting faults Interrogating alarms Receiving incoming information

Inter-rater reliability analysis of the categorization scheme was tested using the Cronbach's Alpha test. Results showed $\alpha = 0.796$, indicating that there was a good degree of consistency between the two independent categorisations.

Results for Company A

Each of the interview statements for each of the roles were classified into the LOAH taxonomy. Table four shows the total frequency count of interview statements for each role at each level of abstraction, together with the percentages. There appear to be some differences in the percentages of statements made at the five levels between nine roles in the control room. For example between team leader roles (e.g. EME SSE & TME) and the operational roles (e.g. NDE RME GDE TDE & RE). This offers some general support for the idea that different roles in the control room work at different levels of system representation.

Table 4. Summary of results for company A

Level	PSM	EME	SSE	TME	NDE	RME	GDE	TDE	RE
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
5. FP	21 (27)	25 (13)	12 (12)	21 (24)	28 (8)	11 (7)	7 (4)	9 (8)	5 (3)
4. AF	19 (24)	62 (32)	31 (31)	17 (19)	64 (18)	34 (23)	16 (9)	9 (8)	1 (0)
3. GF	24 (30)	62 (32)	33 (32)	28 (32)	100 (27)	41 (28)	39 (21)	35 (30)	39 (23)
2. PF	15 (19)	30 (16)	26 (25)	20 (23)	79 (21)	35 (23)	49 (27)	28 (24)	51 (30)
1. P	0	13 (7)	0	2 (2)	94 (26)	28 (19)	70 (39)	36 (30)	76 (44)
Total Count	79 (100)	192 (100)	102 (100)	88 (100)	365 (100)	149 (100)	181 (100)	117 (100)	172 (100)

The differences between the roles and levels are explored each abstraction level.

Level 5 – Functional Purpose

At this level the only difference found was between the PSM and SSE. The observed proportion of statements for PSM at level 5 are higher than the SSE (27% compared to 12%). The observed proportions of statements for the EME and TME were more or less equal. Generally the more operational the role, the less likely that engineers were explaining their work at this level of abstraction, with the exception of the NDE, whose proportion of statements at this level was higher than one would expect. In fact the NDE had a significantly higher proportion of statements at level 5 than other roles within the same role group, namely the RME, TDE and GDE. As expected the NDE also showed a higher proportion of statements at this level than the role of the RE.

Level 4 – Abstract Function

At this level there appeared differences between the team leader roles. The energy management roles were significantly higher in proportion of statements than operational roles and management; EME score was significantly proportionally higher than that of the PSM. Also a higher proportion of statements was found at this level for SSE than the PSM. The operational roles appeared to denote fewer explanations at this level, with the exception of the NDE. Again NDE's spent a higher proportion of statements at this level compared with all other roles at the same level, (e.g. RME, GDE and TDE). As expected the RE showed a lower proportion of statements at level 4 than any other role, as depicted by comparison with the TDE.

Level 3 – Generalised Function

It would appear from the total frequency scores (see table four), that as one moves down the abstraction hierarchy, the frequency of statements were lower within the team leader roles and higher within the operational roles. There are exceptions however, such as between the PSM and EME, where the EME scored a higher proportion of statements. The number of statements within and between the operational roles (e.g. RME GDE TDE & RE) were approximately equal apart from the NDE, whose number of statements was higher at this level than that of any other role both between group roles (e.g. RE and NDE) and within group role, (e.g. NDE and RME).

Level 2 – Physical Function

At this level, the managing roles (e.g. PSM, EME, TME & SSE) had proportionally less statements than the operational roles (e.g. NDE RME GDE TDE & RE). However, the EME's proportion of statements was higher than the PSM's. As management status decreased, so did the proportionate of statements at this level, although the NDE's proportion of statements was still higher than that of the role of the RE. At this level there were also within group differences, for example between NDE & GDE.

Level 1- Physical Form

At the lowest level, two of the management roles (e.g. PSM & SSE) had no statements. It was apparent from the frequency scores that there were fewer explanations at this level by managers and team leaders. The EME scored highest proportion of statements within the managers roles, but this was still significantly less than compared to the operational role of the RME, (e.g. EME and RME). Overall the NDE's frequency of statements was proportionally higher than others within the same role group and more than that of other role groups (e.g. RE and NDE).

Discussion for Company A

Generally the data showed that the level of explanation classified in terms of the abstraction hierarchy corresponded to engineers' position within their organisation. For example, the PSM's who are responsible for a system control team of approximately 22 people, explained their work in terms of the functional and abstract levels rather than in terms of physical functions and form, (see table five).

Table 5. Summary of frequency count as percentage at each level of abstraction

ABSTRACTION LEVEL	PSM	EME	SSE	TME	NDE	RME	GDE	TDE	RE
Functional Purpose	High	Medium	Medium	Medium	Low	Low	Low	Low	Low
Abstract Function	Medium	High	High	Medium	Medium	Medium	Low	Low	Low
Generalised Function	High	High	High	High	High	High	Medium	High	Medium
Physical Function	Medium	Medium	Medium	Medium	Medium	Medium	High	Medium	High
Physical Form	Low	Low	Low	Low	High	Medium	High	High	High

Key:

Over 25% = High	High
Between 10 & 25% = Medium	Medium
Less than 10% = Low	Low

The reason for the higher proportion of statements at the highest level of abstraction for the PSM is easily explained. The PSM's task is to monitor the whole control room, anticipating any problems that may effect the safe secure and economic operation of the transmission system. They are also responsible for risk assessment, setting policy, monitoring commercial strategy and all operations, making sure that the system is being operated within limits. The PSM very rarely has to take an operational role within the control room, unless there is an emergency event.

The role categories that make up the team leaders, (e.g. PSM, EME SSE & TME) tended to have proportionally higher frequency counts at the top levels of the abstraction hierarchy than that of the more operational roles, (e.g. RME GDE, TDE & RE). The exception was the NDE, who from the results showed higher scores at both the functional and abstract levels of the hierarchy than their colleagues in the same operational type of role, (e.g. TDE, RME & GDE). In fact at level 5 (functional purpose), the NDE's scored higher counts than the higher role group of the SSE. The NDE's were as frequently at the top level of abstraction as the PSM's and EME's. They were also more active at the lower levels than their senior counterparts however, as well as their colleagues within their own status groups. It appears that the NDE's have a broader spread of information requirements than their colleagues in the control room.

Generally the energy management team (EME, NDE & GDE) appear to have a broader scope in the abstraction hierarchy than the transmission operations team (TME & TDE). This is specifically noticeable between team leaders (e.g. EME & TME) as the EME explains more of their work at the abstraction level (4), and at the generalised functional level (level 3). This may be due to individual differences from the particular participants we interviewed, however initially the data incorporated 4 TME's and only 3 EME's. It may be that these role categories need to be investigated further.

The strategy team (SSE, RME & RE) seem fairly well balanced across the abstraction hierarchy, although the RME's had proportionally a higher number of explanations overall than their SSE leaders, significantly so at the physical form level, (level 1). This is perhaps not surprising as the RME has a more 'hands on' role than the SSE within the control room. The RE's, spend an equal amount of time as their RME colleagues at the generalised functional level and significantly more at the two lower levels.

At the lower end of the abstraction hierarchy, results showed that the RE was on a par with the GDE, apart from levels 4 & 5, where the GDE scored slightly higher counts, significantly so at the abstraction level, (level 4). In contrast, the TDE whose job is very hands on involving switching, monitoring and auditing the transmission system, appears to be spending significantly less time at the two lower levels than the GDE, albeit they are at the same status level within the control room.

Overall caution must be exercised when interpreting this data, as it must be pointed out that it was only possible to interview a small sample of engineers from each role. It is very obvious from the scores that the NDE's role appear to have the most to consider at all levels and it is suggested that the work load of this role category be further investigated.

Results for Company B

From the total frequency count in table six, it appears that there are some differences between the three roles within company B. The GOC who is equivalent to a team leaders role in company A (e.g. .EME, TME & SSE at NGC), and would expect to have a higher proportion of statements at the top end of the abstraction hierarchy. It could be expected that the operational GOE would have higher proportion of statements at the lower part of the LOAH. The results are presented in table six.

Table 6. Summary of results for company B

Level	GOC	GOE Strategy	GOE Operations
	(%)	(%)	(%)
Functional Purpose	20 (8)	9 (3)	1 (0)
Abstract Function	47 (20)	45 (15)	31 (9)
Generalised Function	74 (31)	85 (28)	75 (21)
Physical Function	66 (28)	85 (28)	111 (31)
Physical Form	32 (13)	76 (25)	135 (39)
Total Count	239 (100)	300 (100)	353 (100)

The differences between the roles and levels are explored each abstraction level.

Level 5 – Functional purpose

The role of team leader (GOC), showed a significantly proportion of statements at level 5 than the role of the GOE's, as expected. There was also a difference between the GOE roles; the strategy engineer producing more statements at this level than the operations engineer.

Level 4 – Abstract function

There were small differences found between the three roles at this level, with the operational GOE showed the lowest proportion of statements.

Level 3 – Generalised function

At this level, the proportion of statements were more or less equally distributed across roles.

Level 2 – Physical function

No real differences were found between roles at this level, although the GOC had the lowest number of statements, with the strategy GOE showing more than the operations GOE.

Level 1 – Physical form

At the lowest end of the abstraction hierarchy, a large difference between roles was found. The GOE in operations had higher proportion of statements than the strategic GOE. The GOC had the lowest proportion of statements when compared to the other two roles.

Discussion for Company B

Due to differences in organisational structure from company A, company B runs four separate area control centres, of which only one took part in this study. Therefore there were only three role categories investigated, as shown in table seven.

Table 7. Summary of frequency count as percentage at each level of abstraction

ABSTRACTION LEVEL	GOC	GOE Strategy	GOE Operations
Functional Purpose			
Abstract Function			
Generalised Function			
Physical Function			
Physical Form			

Key:

Over 20% = High	
Between 8 & 20% = Medium	
Less than 8% = Low	

A summary of the results in table seven, shows the percentage total frequency count at each level of abstraction for each role and gives a more global picture of the differences. The results showed significant differences at the highest level of abstraction across the three roles. The GOC's whose function is one of team leader, explained their tasks in terms of overseeing and managing the whole process (level 5) more than the other two roles. The GOE (operations) had much fewer explanations at this level than the GOE (strategy).

At the abstract functional level (level 4), the scores for the GOC and GOE (strategy), were on a par, and not significantly different from the GOE (operations) engineer. This may be explained by the fact that the GOC tends to work next to the GOE (strategy) engineer and is constantly overseeing demand fluctuations and anticipating problems with respect to optimising system balance.

At the generalised functional level (level 3) no significant differences were found and scores were fairly equally distributed across roles.

At the physical functional level (level 2), although the GOC results were lower, there were no significant differences between roles. This was surprising, and indicates that the GOC has a fairly ‘hands on’ function and more so than similar roles at company A. It also indicates that all three roles spend an equal amount of processing at this level, albeit the GOE (operations) score was slightly higher.

At the lowest level of abstraction, results showed significant differences between roles. The GOC’s explanations at this level were less than the other two GOE’s. The GOE (operations) had significantly more explanations at this level than their strategy colleagues, at the same status level.

Generally, it was observed that the GOC’s were explaining their role at a more abstract functional level. It is suggested that they may be too involved at the lower levels and distribution of tasks may need to be addressed, specifically with the strategy engineer Again, need for caution in interpreting this data is reiterated, due to the relatively small samples interviewed.

Conclusions for the levels of abstraction hierarchy

From this study three main conclusions for further consideration in research into the LOAH may be drawn. First, we offer confirmatory evidence from a field study in control rooms in the energy distribution industry. This confirmatory evidence adds to the initial pioneering work of Rasmussen (1974), to those following in his tradition (e.g. Goodstein, Andersen & Olsen, 1988; Vicente, 1997, 1999). Analysis of the reliability statistics suggests that people are reasonably good as classifying the data into the LOAH categories. This is a promising finding, as it could pave the way for cross-validation studies for analyzing the representation of complex systems held by teams in a variety of domains (such as military command and control, air traffic control, and networked rail signaling systems). A categorization scheme was proposed for use in the energy distribution industries, which can lay claim theoretical validity. Second, this study also undertook another way of adapting LOAH, considering the social dimensions of people and how this interrelates with specific tasks within each role category. Third, having shown that there are differences in the way people categorise their tasks into the LOAH, which seem to be related to role type and position in the organisational hierarchy, it may be proposed that information displays could be designed so that they present the data at different levels in order to support their tasks and the different roles.

We suggest that our research adds a social dimension enhances the LOAH model, as it is an important factor, particularly when people are operating as a team. The research shows all of the levels are comprehensively covered, but only when one considers the whole team interacting. This team model is distinct to the contextual control model developed by Hollnagel (1993), as it suggests that different people in the control room are operating at different levels, appropriate to their work. As a general model, we would suggest that team managers are working predominately at level 5 (functional purpose), supervisors are working predominately at levels 4 and 3 (abstract function and generalised functions), and operators are working predominately at levels 2 and 1 (physical functions and physical form). Company A had more team members and more role specialisation. This seemed to lead to more discrimination in terms of the levels of abstraction that roles fell into. Conversely, company B had fewer team members and less role specilisation which was accompanied by greater overlap between the levels. This lend support from team work studies based on the LOAH that have been conducted in two other domains (Gualtieri et al, 2000; Hajdukiewicz et al, 2001).

This extends the social and role dimensions into interface design. Vicente (1995) has shown how individuals may traverse through the LOAH whilst solving problems. We are suggesting that different people in the control room may require access to different representations of the process in order to work more effectively. As tables four and six illustrate, the general trend is that managerial and supervisory roles in the organisations may benefit from more abstract representations and people in hands-on roles may benefit from more concrete representations. Although this may not be an unexpected finding, it does suggest that different information representations might be required to those already in service. At present, all groups have the same sort of representation of the process albeit with a hierarchical access to increasing complexity. Some systems have zoom and pan functions, but essentially the information represented could be classified at level 3 (i.e., the generalized function level). Displaying information at the other levels is quite complex (Stanton et al, 2001).

The idea of mapping level of abstraction on to system decomposition is embodied in Rasmussen's original proposals for describing work in socio-technical systems, as has been further explored by Vicente (1999). He shows how the LOAH together with a systems representation can be used to illustrate the decision space that people traverse when solving problems. Despite the fact that the examples tend to present the work of a single person, one can imagine this being extended to a team or group of people working together. In which case the decision space will be traverse by a number of individuals. In our analysis, we suggest that people only occupy part of this decision space, depending upon their role. This means that each role in the control room is only part of the distributed problem solving system which comprises the team plus the technological system supporting their activities. We can think of these problem solving activities as cognitive-baton passing, where the problem is handed down the command change as it gets re-specified by each role, from the abstract to the physical. This similar to the idea proposed by Vicente (1999), but this decision space is for a team rather than an individual. The degree of overlap of the decision spaces might prove to be an effect measure of team coordination and cohesiveness. Certainly gaps in the decision space might prove problematic, as indeed might too much overlap. Gaps would require someone to identify that part of the distributed problem solving system is missing whereas too much overlap would mean that responsibility for the problem solving was ambiguous. Gaps in the distributed problem solving system might mean that problems are poorly specified, or at least not specified to the appropriate level before they are handed over to the next member of the team. /These ideas have yet to be fully explored and should be subjected to further research.

The differences between the two energy distribution companies are made apparent when comparing the two team decision spaces. The energy distribution problem for company A is rather more complex than that for company B (due to the inherent complexities in the different types of energy being distributed – electricity versus gas), and this complexity is reflected in the two different decision spaces. Despite these differences, both companies have structured their work so that each role form part of the distributed decision space.

Matching the team role to the representation might be an overly constrictive approach to interface design, but allowing members of the team to have access to different representations of the process relevant to the task that they are controlling may be more fruitful. Future research should bear the role of the team member in mind when applying the LOAH, as this is highly likely to have an effect on their results. Human supervisory control is, after all, a team activity (Hollnagel, 1993). It is hoped that this study will stimulate further investigations into the LOAH in other workplace domains.

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