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Skill, Participation, and Competence: Implications of Ecological Interface Design for Working Life

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Cognitive Engineering Laboratory

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ABSTRACT

In this thesis, the authors attempt to overcome the narrow focus of traditional human factors analysis by examining the social implications of a particular human factors framework for interface design for complex systems: ecological interface design (EID). Recent empirical studies were reviewed to explore EID's potential implications for working life. Three sets of theoretical implications for working life, arising from these empirical studies, were examined. They are: decision latitude, competence (training), and skill enhancement. Empirical evidence and case studies were then reviewed to examine links between the social impact of computer-mediated work and the three sets of theoretical implications. Conclusive evidence demonstrated that the increased degrees of freedom for problem solving provided by EID are a necessary precondition for a healthy and high quality working life. A number of the case studies exhibited a training philosophy consonant with EID's implications for training: to effectively use an EID interface, people must be flexible and adaptive thinkers. It is important for an organization to implement such a training philosophy in an environment where workers have a high degree of autonomy. EID's rich perceptual feedback corresponds to the skill enhancing feedback examined in the case studies. Rich perceptual feedback, coupled with increased worker autonomy, acts as a tool for skill enhancement. EID supports implicit design principles that are consistent with a positive impact on the quality of working life.

Chapter 1: Introduction

1.1 Human Factors Engineering

The profession of human factors, or ergonomics, has experienced an exponential growth in its numbers in the past 20 years. The International Ergonomics Association represents over 15,000 human factors practitioners from 44 countries (Levitch 1994); these individuals can be found throughout industry, government and universities. However, to understand the importance of human factors engineering, one must be able to describe it in a manner that captures the essence of the profession.

Gerald Levitch defines human factors engineers as "practitioners of the science of optimizing all aspects of home, work and leisure activities for people's comfort, safety and performance. They may be engineers or psychologists, or a combination of the two . . . Ergonomics deals with the interface between people and machines." (Levitch 1994) Similarly, Christopher Wickens feels that the essence of human factors is the appreciation of the nature of human interaction with systems -- particularly human performance and its limitations (Wickens 1992a). A broader view is proposed by Alain Wisner. According to Neville Moray, Wisner calls for an "anthropotechnologie" that consists of

> a true "systems approach" whose requirements went far beyond the kind of systems approach which is common today and which is largely founded on military ergonomics . . . He called for the integration of many disciplines, not just the application of ergonomics, but cooperation with psychology, sociology, and anthropology, with engineering, economics and financing, and even politics. (Moray 1994, 1)

Moray goes on to describe a possible goal for human factors: "The task of ergonomics is to design a life style support system . . . to reduce the severity of global problems, taking into account cultural and environmental differences as necessary." (Moray 1994, 10)

Common elements of human factors engineering can be extracted from the aforementioned descriptions. The role of a human factors engineer revolves about the analysis and design of systems which mediate the interaction between humans and machines. The focus of analysis can be approached on a micro-level, for example dealing with anthropometric data and the design of physical characteristics of work stations, such as chair height, video display terminal viewing angles, and so on. On a macro-level, the practitioner's focus is often on the interaction between operators and their work environment within the context of larger, complex industrial systems. An example of a macro-level approach would be the cognitive work analysis, design, and evaluation of the BOOK HOUSE Project (see Pejtersen and Nielsen 1991), a public library information retrieval system.

Within these different levels of analysis, a human factors engineer would be traditionally concerned with issues of safety, human performance and comfort; focusing almost exclusively on the individual human operator and their micro-level environments and ignoring macro-level organizational and social environments.

Information processing theory, a field in which a substantial portion of cognitive ergonomics is grounded, has often been ignorant of contextual issues (Gardner 1985), particularly with regard to the environmental and social contexts. Like most scientific disciplines, information processing theory is founded upon empirical investigation, a method of inquiry that, through its need for the falsifiability of truth claims, requires highly controlled experimentation. An abstracted approach such as this ignores the reciprocal interaction between the operator and her social and physical environment. Hence, there has been comparatively little mention of the social implications associated with human factors work within the field, even though other disciplines, for instance sociology and social epidemiology, have a great deal to contribute.

To understand the shortcomings of context-free approaches, the prevailing world-view that supports them must first be examined.

1.2 Paradigm and Practice: Current Approaches to Work Design

Central to the understanding of the prevailing world-view in workplace analysis and design is an analysis of the values that motivate such efforts. Although scientific inquiry appeals to objective truth, the interpretation of any truth claim depends on the underlying value judgements (Desjardins 1993). With particular regard to the engineering profession, W.H. Vanderburg recognizes that "the judgement whether the introduction of a new technology into a particular context has been largely a success or failure depends on the values used in the assessment." (Vanderburg 1993a, 67) He makes an important distinction between two classes of values: performance values and context values.

Performance values such as labour productivity, efficiency, and gross national product (GNP), are the traditional output-input measures used by management and engineering to optimize the performance of abstract entities, such as organizations and departments, as well as entities with a more concrete existence, such as production lines, individual workers, and machinery. Much of modern society's technological advancement has been grounded in the optimization of these measures (Vanderburg 1993a).

Although necessary in some levels of analysis, particularly in a resource scarce world, performance values have been applied extensively at all levels of analysis while being silent with respect to issues involving the broader societal and ecological contexts. With reference to the design of production facilities, Vanderburg acknowledges the pivotal role played by performance values and measures, this type of design being

> primarily guided by output-input measures, with mitigation technologies added on later to meet whatever occupational health and safety . . . or other regulations apply. Considerations of context compatibility will tend to be fairly peripheral and "after the fact" or "end-of-pipe". (Vanderburg 1993b, 27)

Examples of "end-of-pipe" approaches include the use of mitigation techniques that range from smokestack scrubbers and catalytic converters to psychological counseling for employees suffering from the effects of a stressful workplace.

Context values, which include values such as health, self-determination, and sustainability, are concerned with context compatibility. For example, the context value health is "a state of complete physical, mental and social well-being, not merely the absence of disease or infirmity." (Vanderburg 1993a, 68) These values have been largely ignored even though they are essential to the creation of a 'healthy' workplace, which itself is an essential ingredient of a healthy society. Ergonomists have used certain context values such as health to guide their designs, but a micro-level approach to analysis in such an endeavour has been traditionally used. For example, the notion of healthy work as the absence of physical disablement (e.g., repetitive strain injuries) at the level of the individual workstation illustrates an important, but limited, approach.

Investigation of the dominant world-view and its associated ignorance of context warrants the introduction of the notion of a 'paradigm'. Thomas Kuhn (1970) has coined the word 'paradigm' for conceptual systems that dominate the world-view of scientific communities during specific historical periods. A dominant paradigm can be extremely powerful; it not only defines what reality is but also "what is not and cannot possibly be." (Corbett 1991, 5). As a result, research that challenges the dominant paradigm tends to be suppressed. This had been the state of workplace design until research began to produce data and recommend approaches that were incompatible with the dominant paradigm. After many years of this, the field has progressed into a stage which may be close to a paradigmatic crisis. A new, dominant theory may emerge from this crisis, thus bringing the cycle full circle.

The dominant paradigm in scientific thought is closely related to the Cartesian world-view (Ehn 1988) or mechanistic paradigm. The mechanistic world-view was so successful initially that it became the dominant influence for nearly all scientific thinking. This technocentric attitude places machines and technically mediated communication before consideration of human beings and personal interaction in systems design. Bjorn-Anderson and Kjaergaard call such systems 'people-driving' (Nickerson 1992). Workers are treated as cogs in the machinery; their work is highly structured and tightly arranged with limited decision latitude.

The application of the mechanistic world-view to management was pioneered by F.W. Taylor, the father of scientific management. Taylor explained his objectives for creating scientific management in the following way:

First. The development of a science for each element of a man's work, thereby replacing the old rule-of-thumb methods.

Second. The selection of the best worker for each particular task and then training, teaching, and developing the workman; in place of the former practice of allowing the worker to select his own task and train himself as best he could.

Third. The development of a spirit of hearty cooperation between the management and the men in the carrying on of the activities in accordance with the principles of the developed science.

Fourth. The division of the work into almost equal shares between the management and the workers, each department taking over the work for which it is better fitted; instead of the former condition, in which almost all of the work and the greater part of the responsibility were thrown on the men. (F.W. Taylor cited by Barnes 1980, 14)

The fundamental assumption of Taylorism is that workers produce more and become more efficient if given monetary rewards. Taylor developed the notion of a 'standard' worker, with standardized routines, wages, and hours, a belief rooted in the possibility of accurately abstracting the worker from her environment. Such an abstraction ignores relationships with supervisors and fellow workers. This dehumanizes the worker; she is considered nothing more than an extension of the machinery of production.

Taylorism has resulted in the removal of worker's knowledge from the labour process. This has led to a division of labour: the separation of the 'hand' from the 'brain'. This division of labour has created heightened tensions between the forces of management and labour. The rationale behind this division is grounded in the belief that all knowledge can be verbalized and formalized in an algorithmic manner.

An important question is whether the aforementioned mechanistic paradigm has had a significant influence within human factors and, more specifically, human-computer interaction (HCI). We purport that there in fact has been a large reductionist influence within human factors, manifesting itself as an emphasis on the products of design instead of the process of design. However, recent trends in HCI, such as user-centred design (see Eason 1992; Eason 1994; and Ehn 1988), and certain theories in the field of experimental psychology, such as ecological psychology, seem to be heading towards a less mechanistic conception of human performance, one in which context considerations seem to play a more primal role.

In a paper entitled, "From Human Factors to Human Actors", Liam Bannon (1991) critically assesses traditional human factors approaches and then provides a vision for a more "fluid and pragmatic" approach to HCI and system design, a vision that calls for an alternative design paradigm. Bannon contends that human factors' long tradition of involvement in the design and implementation of computer systems has often slighted some very important workplace issues. Two such critical issues have been the underlying values and motivation of the workers in their work settings. Part of this problem can be traced to an implicit view of people: at best, they are seen as "sets of elementary processes or 'factors' that can be studied in isolation in the laboratory " (Bannon 1991, 25); at worst, they are seen as "idiots" who must be protected from the complexity of machines. Consequently, Bannon believes that people must be understood as "actors" in their work situations, a term that we will adopt in lieu of "human operators". This concept of human actors, with their sets of skills, shared practices, and varied work experiences, requires new ways of studying these multi-layered and multi-faceted work domains, domains that are often too complex for controlled laboratory studies.

The aforementioned tendencies have been compounded through the coupling of organizational influences with a rigid scientific approach, where

> one often finds that [human factors engineers] have little influence over the design process, and are often regarded as "add-ons" by the engineering staff. This state of affairs has sometimes been encouraged, unfortunately, by the human factors personnel themselves, who often seem unwilling to understand the complete project or product, but focus on the narrow aspects that are adjudged to require human factors input. (Bannon 1991, 40)

As well, HCI's focus on the individual user has neglected the complexity of coordination and cooperation in the workplace. We agree with Bannon's recommendation that, instead of constructing fully automated systems, what is needed is the design of systems that "support . . . workers in their activities." (Bannon 1991, 35)

To conclude, we have identified that a mechanistic world-view has had an important influence within human factors, leading to the ignorance of the broader social context and consequently emphasizing performance values. This view points the way to an interdisciplinary[1] and holistic approach to systems design.

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[1]Or, equivalently, transdisciplinary.

1.3 Towards a Holistic Approach to Analysis and Design of Work Domains

What does a holistic approach to work systems design entail? The first and most important step in the path to holistic thought is a discussion of the interpretation of parts and wholes. Imagine, for instance, a human actor and the technological system with which she interacts. Although the human actor and the technology with which she interacts can exist on their own, it would be short sighted to consider them as separate entities. Each component is a "whole" on its own. However,

> each does not exist in their own space and time, interacting with each other across external boundaries. They interpenetrate and are "enfolded" into each other. (Vanderburg 1993a, 56)

To gain a proper understanding of the actor requires not only a focus on the actor herself but also an understanding of the technology interacted with, the social interactions with fellow workers, and other aspects of the working environment. Workers are affected by their surroundings and certain characteristics are a result of this interaction with their 'tools'. Hence, the whole cannot simply be derived from the summation of the parts.

Analysis of wholes can proceed in two directions. First, the whole can be seen as being part of a larger whole. Secondly, the whole under observation is constructed of smaller wholes. These two directions of analysis can thus be seen as a shifting of focus, a shifting that can continue for many levels in either direction (see Figure 1 below).

Figure 1. The shifting focus between wholes can be imagined as traversing a set of nested circles. Level of abstraction increases as one moves outwards.

Through this paper, we attempt to overcome the narrow focus of traditional human factors approaches by holistically examining the impact on working life of one particular human factors framework: the ecological approach to interface design as put forth by Rasmussen and Vicente (Rasmussen and Vicente 1989; Vicente and Rasmussen 1990, 1992). It is important to note that the ecological approach to interface design has not been designed with explicit social values in mind. Its scope has concentrated on safety and performance. However, due to its effects on human-machine interaction, the social characteristics of the workplace are also, by necessity, affected. As working life is inseparable, enfolded, into the greater whole of existence, any effect on working life will influence other spheres of existence such as health (psychosocial effects), social interaction, organizational functioning, and so on. It is this realization of interdependence that leads us to examine working life, an area often glossed over in micro-level analyses of performance. By limiting our investigation of the impact of this framework on the context of working life, we are undoubtedly excluding other effects. However, this is an important step in understanding the implications of ecological interface design beyond laboratory settings.

Heather Menzies, in discussing some forthcoming national programs in building a technological infrastructure, identifies some of the overlooked effects of computer- mediated communication. Specifically, computer-mediated communication structures our choices "and, in doing so, [it] structures our lives and our consciousness through the assumptions built into the software." (Menzies 1994, 24) In computer-mediated work, interface design is crucial as it structures the worker's interactive environment. The interface becomes a new environment, the worker's "surround" as Marshall McLuhan has stated. Consequently, an interface based on the principles of ecological interface design will have an impact on the human actor's work environment.

The next chapter introduces the ecological interface design framework, along with the events leading up to is inception and results from recent empirical studies.

Chapter 2: Ecological Interface Design

2.1 The Rise of Complex Industrial Systems

With the advent of the rapid growth and development of technology in this century, the complexity of analysis and design for supporting the human actor in complex operational settings has increased. The complex environments in which many people now work share certain characteristics.

To begin with, high degrees of risk are associated with certain complex work domains. This risk stems from the fact that "inappropriate control actions can have catastrophic consequences" (Vicente and Rasmussen 1990, 209).

Secondly, these new environments are tightly coupled, interactive systems. Different parts or subsystems have a strong dependence on one another. Changes in one element of the system can cause changes in another, leading to synergistic effects that often take place between technologies in complex environments (Vanderburg 1993a). When technologies interact in such a manner, the outcome of the interaction is not simply the sum of the individual interactions. As a consequence, unpredictable results can occur. This is because "we have produced designs so complicated that we cannot anticipate all possible interactions of the inevitable failures" (Perrow 1984, 11).

As complex settings are often highly dynamic and have long time constants, the third characteristic can be identified as delayed feedback from the system. It is not possible for the perception-action loop to be continuously updated in light of such a situation. This causes operators to develop a different type of control strategy (Vicente and Rasmussen 1990).

These systems are often highly automated and automatically controlled because of their complex nature. The human actors' roles are usually supervisory ones; their task is to monitor the state of a particular system and therefore demands are mainly placed on the their perceptual and cognitive abilities (Vicente and Rasmussen 1990).

Finally, when fault situations occur the actor must deal with these faults. Vicente and Rasmussen declare

> It is . . .[the human operator's] responsibility to improvise and adapt to the contingencies of an abnormal event quickly to ensure system safety. Because their normal control procedures no longer apply in these cases, operators must generate an appropriate response based on a conceptual understanding of the system. (Vicente and Rasmussen 1990, 210)

To facilitate the forthcoming discussion of ecological interface design and its role in supporting human actors in their control of complex systems, we must now turn to two possible approaches that support this theoretical framework of interface design.

2.2 The Ecological Approach

Mention the word ecology and many people will either expect a discussion of the diverse biological systems in stagnant Muskoka ponds to ensue; or they may look nervously about, wondering which of the nearby great oaks are marked for the paper mill and whether the soon-to-arrive activists will chain themselves to the trees or instead lay down in the path of logging trucks. The ecological approach under discussion, however, arises from the field of experimental psychology.

To reveal what is meant by an ecological approach, consider the notion of an ecological attitude,

> an attitude toward theory and research that fully appreciates the world as the source of information by which animals and humans perceive events, comprehend circumstances, and act successfully in the service of biological, psychological and

social needs. (Shaw and Bransford 1977, 2)

This attitude seeks to supplement the traditional psychological approaches (e.g., information processing theories), which emphasize the how of cognitive processing, with an emphasis on the what: the nature of processed information (Shaw and Bransford 1977). An ecological perspective, as cultivated by Brunswik and Gibson (Vicente 1990), studies the interaction between an organism and its environment.

Perception is central to understanding Gibson's approach to ecological psychology. Gibson held a belief in direct perception wherein organisms directly perceive higher order affordances, that is, possibilities for action, i.e. they avoid the integration of lower level information through mediating levels of information processing by constructing higher-level goal-relevant information in a direct fashion. This direct perception of affordances provides "a means of selecting the appropriate action to attain a goal, and the concept of an affordance relates perception to action" (Rasmussen and Vicente 1989, 531). This perception-action loop results in teleological behaviour.

With respect to ecological interface design, the process being controlled through use of the interface is the constraint providing environment, and the relevant constraints are represented as affordances in the interface. This allows for the possibility of utilizing direct perception in such a manner as to allow the system to be controlled "without any mediated decision-making." (Rasmussen and Vicente 1989, 532).

2.3 The Skills-Rules-Knowledge Taxonomy

Another approach that supports ecological interface design can be found in Jens Rasmussen's Skills-Rules-Knowledge taxonomy, hereafter called the SRK taxonomy (see Rasmussen 1983, 1990; Rasmussen, Pejtersen, and Goodstein 1993; Sanderson and Harwood 1988; Vicente and Rasmussen 1992).

The SRK taxonomy is a model of human performance wherein three levels or classes of cognitive control interact in a dynamic manner. Neville Moray (1988) sees this qualitative model as a paradigm shift in engineering psychology from rigorous quantitative models. The purpose of the SRK taxonomy is to represent human performance in a format that facilitates the design of support systems and training programs in complex, high-risk environments (Rasmussen 1990; Olsen and Rasmussen 1989), particularly with the aim of avoiding error producing behaviour.

This taxonomy models the cognitive control of human performance, "a control function organized on several levels of perception, action, and information processing," (Rasmussen, Pejtersen, and Goodstein 1993, 110) with three levels: the skill-based level, the rule-based level, and the knowledge-based level.

The skill-based level supports skill-based behaviour (SBB). This level represents "sensorimotor performance . . . that, eventually after a statement of intention, take[s] place without conscious control as smooth, automated and highly integrated patterns of behaviour." (Olsen and Rasmussen 1989, 13) This class of performance is modeled as a multi-variable, continuous and flexible control system based on feedforward, or intentional, control. SBB corresponds to automatic performance. Olsen and Rasmussen believe that "the flexibility of skilled performance is due to the ability to compose the sets suited for specific purposes from a large repertoire of automated subroutines." (Olsen and Rasmussen 1989, 13) This statement seems similar to the beliefs of computationalists, but an earlier paper clarifies this notion. In a manner similar to that of Vanderburg's (1985) concept of a mental map, Rasmussen believes that this sensorimotor performance occurs

with reference to a dynamic internal map of the environment . . . the behavioral complexes necessary to perform an intention to "pick up a glass" or "place finger on nose" are integrated wholes which cannot be decomposed into separate elements . .

. (Rasmussen 1983, 259)
James Reason, in summarizing skill-based behaviour, reinforces this view by asserting that such performance is controlled by "stored patterns of preprogrammed instructions represented by analogue structures" (Reason 1988, 39).

The rule-based level supports rule-based behaviour (RBB). When performing at this level, the human agent consciously controls the sequence of actions in the task domain through the use of stored rules or procedures

that may have been derived empirically during previous occasions, communicated from other persons' know-how as an instruction or cookbook recipe, or it may be prepared on occasion by conscious problem solving and planning. (Olsen and Rasmussen 1989, 14)

The human agent is explicitly aware of alternative options and has to make a choice amongst them, but the goal of the person's action need not be explicitly formulated. Hence, it is often implicit in the situation. Familiar problems are then tackled through the use of stored IF . . . THEN rules to produce action.

The last level of cognitive control to be considered is the knowledge-based level, which, aptly, supports knowledge-based behaviour (KBB). During unfamiliar situations "for which no know-how or rules for control are available from previous encounters, " (Olsen and Rasmussen 1989, 15) KBB is exhibited. In such a situation, the human agent's purpose is explicitly formulated and a useful plan of action is chosen through the consideration of alternative actions. Trial and error or thought experiments are used as testing grounds for the evaluation of different courses of action. KBB can be seen as a level of functional reasoning wherein the internal structure of the work domain is represented by an explicit mental model. This mental model may take on several different forms, at different levels of abstraction (Rasmussen 1990, 58). Different plans of action are formulated based on the human agent's relational model of the domain built up in her mind.

It is important to note that the cognitive control of the human agent moves flexibly and dynamically amongst these three levels. Regarding the development of skill, that is 'learning' in a given task domain, Sanderson and Harwood (1988) model the progression as a two-dimensional space. Imagine that the horizontal axis is partitioned into the sequence novice, intermediate, and expert. The vertical axis is partitioned into KBB, RBB, and SBB. Expert and novice performance may therefore exhibit interaction between the three levels of cognitive control, but at the expert level the intuitions, mental models, and rules should be more refined.

Rasmussen identifies a general trend in the shifting between levels of cognitive control. When self-instruction is involved, control shifts from knowledge-based to rule-based and finally to skill-based behaviour. This progression may in fact occur in some domains. When instruction from another party is involved, cognitive control moves from rule-based directly to skill-based (Sanderson and Harwood 1988, 29). The knowledge-based level is foregone. This implies that in some instances a mental model is not formulated. Some examples of differing progressions can be seen in the comparison of skiing, which does not involve KBB and seems to progress from RBB to SBB, with chicken sexing, in which cognitive control seems to occur solely at the skill-based level, wherein increased refinement of SBB leads to increased expertise.

2.4 Abstraction Hierarchy

Vicente states that the "abstraction hierarchy is a useful framework for representing a work domain in a way that is relevant to interface design." (Vicente and Rasmussen 1992, 591) That is, the functional relationships between system elements and system goals are made apparent in this stratified framework.

The abstraction hierarchy (AH) consists of a hierarchical representation wherein each level is a complete functional description at a given level of system abstraction. The levels are related through means-ends links. The lower level descriptions represent the means available to achieve the ends represented by the next highest level.

There are a number of psychologically relevant advantages to using an AH to map out the constraints of a work domain. The AH allows people to deal with the often unmanageable complexity of complex systems by shifting from a low and highly detailed level of abstraction "to a higher level of abstraction with less resolution" (Bisantz and Vicente 1994, 109).

Another advantage of the AH is that a problem-solving search can be constrained in a goal-relevant manner. Bisantz and Vicente illustrate this property:

. . . search can be constrained by initiating the problem-solving process at a high-level of abstraction, deciding which part of the system is relevant to current goals, and then concentrating on the sub-tree of the hierarchy that is connected to the subsystem of interest. (Bisantz and Vicente 1994, 109)

To summarize, the abstraction hierarchy is an event independent functional system representation. It presents the possibilities for interaction between various components of the work domain.

2.5 Ecological Interface Design

Ecological interface design (EID) is a theoretical framework for dealing with complex human-machine system interaction on the level of control interfaces (Vicente and Rasmussen 1992). These complex domains have the characteristic that their goal relevant properties are not directly perceivable. As a prescriptive interface design framework, EID prescribes the mapping of system affordances onto an interface. Succinctly put, this theoretical framework tries "to make visible the invisible." (Rasmussen and Vicente 1989, 532)

These affordances are built into the interface through the use of an abstraction hierarchy. Consequently, the human actor can take advantage of the direct perception of the system's affordances to effectively control the system through skill-based behaviour. However, due to the complexity of many industrial systems, one cannot ensure that interfaces can be designed solely by mapping the system's affordances directly onto the interface. In cases such as this, control through SBB must be supplemented by either or both of the two other levels of cognitive control: RBB and KBB. Rasmussen and Vicente summarize these relationships well:

In the natural environment, there is enough intrinsic information in the optical array for interaction to take place at the skill-based level . . . However, the complex nature of process systems implies that the operator will have to resort to higher levels of cognitive control at certain times . . . In order to deal with these situations, EID attempts to make the most of the information that is available in order to offer the operator as much as possible. While the interface is structured to allow operators to rely on lower levels of cognitive control, support for all. . . levels is provided. (Rasmussen and Vicente 1989, 533)

How are these higher levels of cognitive control supported? RBB is supported through a consistent one-to-one mapping between the constraints of the work domain and the cues provided by the interface; KBB is supported through representation of the work domain in the form of an AH which acts as an 'externalized' mental model (Vicente, In Press).

Two basic goals of EID can now be identified:

1. Try to minimize the difficulty of the control task by not forcing cognitive control to a level that is higher than the demands required by the task (Vicente and Rasmussen 1992).

2. The three levels of cognitive control, the skills-, rules-, and knowledge-based levels, are to be supported (Vicente and Rasmussen 1992).

Now, we can turn to examination of the explicit values upon which EID was devised. Vicente (Personal Communication, 1994) has remarked that the closely related values of performance and safety were the driving forces behind the creation of the framework. He reasons that if industrial process control is made safer by the minimization of error, overall process efficiency is maintained or increased[2]. The human actor is empowered to cope more effectively with the complexity of the system and its unanticipated events. This approach stands in opposition to the traditional method for coping with serious error, which has been through the use of rigid procedures. Such an approach limits problem-solving simply because unanticipated events, due to their nature, cannot be foreseen by those that draw up the problem-solving procedures.

2.6 Summary of Experimental Findings

Presently, there have been four experimental investigations into EID interfaces (Christoffersen, Hunter, and Vicente 1994b). Practically all research on EID has been conducted on two closely related simulation systems, DURESS (DUal REservoir System Simulation) and DURESS II (Vicente, In Press). DURESS and DURESS II simulate a thermal-hydraulic process, with DURESS II being an updated, interactive version.

The thermal-hydraulic system consists of two redundant feedwater streams "that can be configured to supply water to either, both, or neither" (Vicente, In Press) of two reservoirs. The objective of the system operator is to satisfy an external and dynamic demand for water while maintaining each of the reservoirs at an assigned temperature, 40^{o}C and 20^{o}C respectively. The system operator has control over eight valves, two pumps, and two heaters to accomplish these goals.

There have been two classes of interfaces designed for the series of experiment centered about DURESS and DURESS II. The first one is based on a piping and instrumentation diagram (P&ID) system representation and can be seen in Figure 2. The P&ID interface provides a physical representation of the system with particular attention being paid to the "current state of all of the components and the goal variables." (Vicente, In Press) This interface is a typical representation of existing process control system interfaces and hence serves as an important control condition in the experiments.

The second interface is based on the principles of EID. The EID interface (Figure 3) consists of a P&ID interface overlaid with additional higher-order functional information. This functional information includes valve flow rates, heat transfer rates, and mass and energy balance information. As well, a one-to-one mapping is maintained between the constraints of the domain and the salient properties of the interface. This characteristic is intended to enhance the extraction of information.

[2]In other words, the prevention of serious accidents (explosions, leaks, and so on) allows plant operation to continue normally and thus efficiently.

Figure 2. P&ID Interface

Figure 3. EID Interface

The first evaluation of EID was conducted using a non-interactive version of DURESS and the goal was to compare the earlier versions of the P&ID interface with the EID interface. This comparison was necessary to determine how well each of these design approaches support problem solving behaviour or KBB. Evidence existed to show that EID provided better support for KBB than the P&ID interface. However, these findings were limited in two ways. To begin with, the subjects were either theoretical experts or novices when dealing with thermal-hydraulic principles. Secondly, the subjects did not interactively control the system. This preliminary investigation was unable to determine whether the advantages of the EID interface would hold if subjects had greater experience controlling DURESS.

The second investigation also involved the use of DURESS. As in the previous study, the subjects were presented with 'canned' scenarios; the subjects did not interactively control the system. Verbal protocols[3] were collected as the subjects tried to diagnose the nature of events presented to them. The results indicate that the more the subjects adopt the top-down "zooming-in" strategy that the AH is intended to support the more accurate their diagnosis. However, the interpretation of these results remains limited due to the experiment's non-interactive nature.

The third experiment overcame the lack of interactive control of the system. The subjects were able to control the system components in a closed loop fashion using DURESS II. As well, subjects were allowed to gain experience in controlling the system by means of practice. Practice time consisted of one hour per weekday for four weeks. Results from the experiment showed that a significant performance difference did not exist between the EID and P&ID interfaces on normal trials after extended practice. However, results did show that the P&ID interface loaded more on the subjects' verbal resources, while the EID interface put a greater burden on spatial resources (Pawlak and Vicente 1994). Additional results showed that using the EID interface led to faster fault detection and more accurate fault diagnosis.

This third experiment revealed two areas in which shortcomings in the EID interface were evident. A need for integrating trend information with emergent feature displays was observed. As well, displays tailored for enhanced perception of system state were not always well suited for recovery from fault situations.

The last experiment was similar to the third; however, it ran over a longer period of time and investigated the main issues in greater depth. Part of this investigation was concerned with addressing a suspicion raised by Wickens (1992b). Wickens predicts that

> an interface based on EID may actually inhibit long-term learning and retention . . . since EID is intended to reduce operator effort by displaying an external visualization of the process constraints, operators are not forced to extensively study and thus completely understand system functionality since it is already apparent in the surface features of the interface. (Christoffersen, Hunter, and Vicente 1994b, 141)

A P&ID interface, which does not present system functionality through directly perceivable features, requires greater cognitive effort for full comprehension of system functionality and its internal relationships. Consequently, the human actor may impose and reinforce her understanding. This could result in improved performance over that supported by an EID interface. The situations where this may occur would be unfamiliar or abnormal situations in which EID is supposed to actually aid the process operator. In other words, by perceiving system affordances through direct attunement[4], the operator has not developed enough deep understanding to

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[3]Verbal protocols are used to evaluate the mental models of the subjects with respect to the system in question. This is accomplished by having the subjects verbalize their thoughts during their experimental trials. (Christoffersen, Hunter and Vicente 1994b, 7)

[4]A process that is similar to neural system conditioning and is responsible for SBB. (Rasmussen and Vicente 1989)

deal with anomalous situations. By utilizing SBB and RBB frequently, the operator may become "accustomed to using the surface features as a crutch" (Christoffersen, Hunter, and Vicente 1994b, 141) and may be unfamiliar with using KBB to deal with these anomalous events. A 'strong interpretation' of Wickens' prediction leads to the conclusion that the P&ID interface would actually be better than the EID.

There is also a 'weak version' of Wickens' argument. This standpoint

> . . . suggest[s] that some EID subjects could become dependent on the perceptual features of the display and that this would negatively affect their performance. (Christoffersen, Hunter, and Vicente 1994b, 142)

The findings of the last experiment were threefold. First, it was discovered that

> there was little difference in the average performance of each interface group on normal trials. However, the P&ID group is generally less consistent, periodically taking much longer than usual to perform the required tasks. (Christoffersen, Hunter, and Vicente 1994b, 136)

Second, it was found that an interface based on EID led to more effective fault management performance "on both routine and non-routine faults, especially in terms of diagnosis accuracy" (Christoffersen, Hunter, and Vicente 1994b, 135). Finally, it was noted that "when combined with a surface approach to learning, the EID interface can lead to a very shallow knowledge base and poor performance" (Christoffersen, Hunter, and Vicente 1994b, 135). With regard to the strong interpretation of Wickens' argument, there is absolutely no evidence to support it. However, the weaker interpretation of Wickens' argument does surface. Christoffersen, Hunter, and Vicente (1994b) note that this surface approach to learning leads to inferior performance, though not worse than the performance attained in the P&ID interface, given that the level of subject motivation is comparable. The authors point out that some of the subjects were well adapted to the system and performed well with the EID interface; Christoffersen et al. suggest that this is due to reflection on the feedback provided by the EID interface, as well as exploration of the system. (Christoffersen, Hunter, and Vicente 1994b, 135) The report concludes that "it seems certain preconditions have to be satisfied to experience the benefits of the EID interface." (Christoffersen, Hunter, and Vicente 1994b, 135)

2.7 Theoretical Implications

There are a number of implications that arise from the theoretical framework of EID and its experimental findings. Three closely related sets of implications relating to the working life of operators can be identified. They are as follows:

1. Decision Latitude and Participation

EID interfaces do not solely support procedural rule-based behaviour. Operators have more degrees of freedom to problem solve and hence should have more decision latitude for their problem solving. The aforementioned implication requires that operators be given more problem solving responsibility in their work domain. As EID requires functional thinking, the operator, out of necessity, must be empowered to fully exploit the available degrees of freedom.

2.Competence (Training Issues)

As a result of the above discussion concerning decision latitude, certain implications for training philosophy are induced. Presently, many organizations involved in industrial process control emphasize procedural thinking. By requiring a shift in operator thinking from a procedural to a functional problem solving mode, the effective use of EID interfaces impacts on traditional training philosophy. That is, people using an EID interface must be flexible, adaptive thinkers.

3. Skill Enhancement

Through the use of an EID interface, operators are provided with rich perceptual feedback. However, to reap the benefits of EID, it seems that operators should have "a willingness and ability to critically reflect upon, and learn from" (Christoffersen, Hunter, and Vicente 1994b, 143) this feedback. Otherwise, there may be a possibility of a deskilling effect as postulated by Wickens.

Taking a broader perspective such as this requires that the relationship between the theoretical implications of EID and issues in working life be examined. Chapter 3.0 outlines the characteristics of the investigation. We then attempt to link empirical findings and case studies to the theoretical implications of ecological interface design with the objective being an assessment of possible implications for working life, such as impacts on the psychosocial character of computer-mediated work.

Chapter 3: Case Investigation of Skill, Participation, and Competence

3.1 Methodology

In this chapter we attempt, through an extensive literature review, to relate the findings of empirical investigations and case studies in computer-mediated work to the three theoretical implications of EID: decision latitude and worker autonomy, competence, and skill. Through this, we wish to generate some conclusions on EID's implications for working life, preconditions for EID's successful implementation, and recommendations, if any, for the prevention of any deleterious effects.

Certain criteria were established to facilitate the selection of material for inclusion in our study. Foremost amongst these criteria is the requirement that there be a substantial component of, or relation to, computer-mediated work. We have attempted to include material that is as recent as possible simply because the use of graphical user interfaces (GUI's) in work settings is a relatively new phenomenon, one that has arisen in the past twenty years. Under this rubric of computer-mediated work, issues of competence and training, skill enhancement/deskilling, worker responsibility and autonomy, social support, and impacts on organizational structure, were important components due to their relationship with the theoretical implications of EID and working life.

Using these criteria, we have identified three categories within the relevant literature. These are: Social Epidemiology and Computer-Mediated Work, Case Study in the Work-Oriented Design of Computer-Mediated Work, and, a slightly more general category, Other Case Studies in Computer-Mediated Work.

3.2 Social Epidemiology and Computer-Mediated Work

In their seminal publication, Healthy Work, Robert Karasek and Tores Theorell (1990) reveal the strong connection between work and health. Standing in sharp contrast to the individualistic clinical approach to worker health, this social epidemiological standpoint examines the dysfunction and disablement ('industrial disease') linked with the psychological and social (psychosocial) conditions of work. Karasek and Theorell outline their book's main emphasis:

This book's primary emphasis on an environmental perspective is unusual . . . the concern for stress-related illness has brought forth more research examining characteristics of the individual (personality, genetics) as causes of illness, which in turn have led to overwhelming numbers of person-oriented cures . . . These solutions seem to offer an easy alternative to complex and difficult labor/management negotiations over workplace control. To avoid the more difficult underlying issues is to deal with the symptoms instead of the causes . . . (Karasek and Theorell 1990, 7)

A growing body of social epidemiological evidence suggests that factors such as motivation, alienation, income, and employment greatly influence the health of workers. In turn, the welfare of a society is strongly dependent on the health of its working population. This demonstrates the interdependent character of the social, economic, and cultural contexts. The broader context of worker health is illustrated in figure 4 below.

Figure 4. The context of worker health.

The evidence presented by Karasek and Theorell in their demand/control model (Karasek and Theorell 1990, 31) illustrates the profound effects that the psychosocial conditions of the workplace have on the likelihood of industrial disease and reduced productivity. This evidence includes cardiovascular disease amongst bus drivers and psychological dysfunction in air traffic controllers (Ham 1990). Of great interest is the possibility that psychosocial conditions may have as great an effect on work health as do the physical conditions (e.g., air-borne contaminants and toxic substances). Naturally, one may ask: which psychosocial conditions are associated with dysfunction and disablement?

Three psychological dimensions that characterize work are identified by

Karasek and Theorell (1990). These are:
decision making latitude -- the degree of control a worker has over work methods (discretion over the skills to be utilized and developed, work pace, and so on),
psychological demands -- quantitative overload (pacing and other forms of time pressure) and qualitative underload (monotonous work, lack of creative input, work is unstimulating), and
social support -- the character of workplace social interaction, including feedback from peers and superiors.
Job strain is related to the measures of the above factors. The greatest job strain can be associated with low levels of decision latitude, high quantitative psychological demands, and low levels of social support. With respect to this thesis, the material covered will primarily consider the relevant factors of decision latitude (skill discretion) and psychological demands. Figure 5 (below) illustrates Karasek and Theorell's (1990) three dimensional model of the psychosocial dimensions mentioned above.

Figure 5. A 3-Dimensional Model of the Psychosocial Work Environment (Karasek and Theorell 1990)

Karasek and Theorell (1990) base this demand/control model on many empirical studies. Some of the studies in the book that support this demand/control model are described briefly below[5].

3.2.1 Swedish Level of Living Survey. (Karasek and Theorell 1990, 123)
This survey comprised a random sample (1:1000) of employed men below the age of 66 who were interviewed about job conditions and health in 1968 (N=1,915) and 1974 (N=1,635). This data had been collected before Karasek and Theorell's group had started to research the link between job conditions and health; they had to rely on statistical procedures to contrast the psychosocial dimensions that were deemed relevant to job demands and decision latitude.

[5] The total number of studies approaches a total at least an order of magnitude greater than what we have presented. We have tried to provide an adequate cross-section.

3.2.2 U.S. Department of Labor's Quality of Employment Surveys (QES). (Karasek and Theorell 1990, 41)
This survey was conducted by the Institute for Social Research at the University of Michigan and was used in conjunction with the 1970 U.S. Census occupation codes for Karasek and Theorell's subsequent analysis. A research team including Karasek, Schwartz, and Pieper (Karasek and Theorell 1990, 336) amalgamated these three surveys into a large database of 4,503 respondents (2,946 men and 1,557 women).

3.2.3 1980 Study of Seventy New York Savings and Loan Associations.
Turner (1980) reviews a study of 1,500 mortgage loan clerical workers that supports the demand/control model.

3.2.4 1979 Study of U.S. Workers in Three Manufacturing Assembly Plants.
Freeman and Jucker (1979) report on a study of 2,600 U.S. workers that supports the demand/control model.

3.2.5 1983 Study of Danish Slaughterhouse Workers.
Sondergaard-Kristensen and Lonnberg-Christensen (1983) report on a study of 7,000 Danish slaughterhouse workers that supports the demand/control model.

3.2.6 1987 Study of Premature Ventricular Contractions (PVCs) in Prison Personnel.
Sixty-two men in four different prisons were studied by Harenstam, Theorell, Orth-Gomer, Palm, and Unden (1987). PVCs were studied with the twenty-four hour recordings of ECG's of these prison personnel, i.e. guards and others. A univariate analysis showed that the lack of decision latitude explained a

statistically almost significant (p=0.07) number of arrhythmias. The less authority the guard had over decisions and skill utilization, the more PVCs were recorded, both at work and during leisure. (Karasek and Theorell 1990, 111)

3.2.7 1960-1962 U.S. Health Examination Survey (HES)
This is clinical database (N=2,409 working men) which represents the "basis of U.S. national statistics on myocardial infarction prevalence" (Karasek and Theorell 1990, 127). Karasek and Theorell use this as a basis for statistical analysis that supports their model.

3.2.8 1971-1973 U.S. Health and Nutrition Examination Survey(HANES)
This is also a clinical database (N=2,432 working men) used by Karasek and Theorell (1990, 127) as a basis for some of their statistical analyses concerning the effects of high degrees of job strain on health.

3.2.9 1977 Study of Males and Females in Five U.S. Companies in Michigan
The demand/control model was used to analyze the productivity of five firms from a range of different industries in Michigan (Karasek and Theorell 1990, 174). These industries consisted of a hospital, a printing company, a research and development firm, and two auto accessory manufacturers. The demand/control model was

evaluated through the use of questionnaires and scales in conjunction with supervisor ratings of productivity (N=228). It was found that productivity was significantly
(p≤0.05) ασσοχιατεδ ωιτη ηιγη φοβ δεμανδσ ονλψ ιφ δεχισιον λατιτυδε ωασ ηιγη. Ηιγ
η φοβ δεμανδσ χουπλεδ ωιτη α λοω λεϖελ οφ δεχισιον λατιτυδε λεδ το δεχρεασεσ ιν
προδυχτιϖιτψ (Καρασεκ ανδ Τηεορελλ 1990, 174).

3.2.10 Στυδψ οφ Σωεδεν∋σ Φεδερατιον οφ Ωηιτε−Χολλαρ Υνιονσ

Τηισ στυδψ προϖιδεδ πρεχισε εϖιδενχε οφ τηε ιμπαχτ οφ χηανγεσ ιν δεχισιον λατιτυ
δε ατ ωορκ ον λονγ−τερμ ηεαλτη στατυσ. Δατα ωασ χολλεχτεδ φρομ α λαργε ρανδο
μ (N=8,700) συρϖεψ οφ φυλλ−τιμε μαλε ανδ φεμαλε ωηιτε−χολλαρ ωορκερσ ιν Σωεδε
ν∋σ Φεδερατιον οφ Ωηιτε−Χολλαρ Υνιονσ ανδ συππορτεδ α ∀συβσταντιαλ χαυσαλ ι
ντερπρετατιον αβουτ τηε εφφεχτσ οφ χοντρολ ον ηεαλτη στατυσ.∀ (Καρασεκ ανδ Τη
εορελλ 1990, 183)

Ωε νοω τυρν το α σπεχιφιχ χασε στυδψ οφ τηε πσψχηοσοχιαλ χονδιτιονσ οφ
χομπυτερ−μεδιατεδ ωορκ χιτεδ βψ Καρασεκ ανδ Τηεορελλ (1990). Ωε τηεν εξαμινε ο
νε φολλοω−υπ στυδψ περφορμεδ αφτερ τηε πυβλιχατιον οφ Ηεαλτηψ Ωορκ χονδυχτε
δ βψ οτηερ ρεσεαρχηερσ.

3.2.11 Εφφεχτσ οφ Χομπυτερ Αππλιχατιον Δεσιγν Παραμετερσ ον Οπερατορ Τασκ Πε
ρφορμανχε ανδ Ηεαλτη

Ατ τηε ουτσετ οφ τηισ στυδψ, Τυρνερ ανδ Καρασεκ (1984) νοτε τηατ δυε το τηε ραπι
δ ινχρεασε ιν τηε υσε οφ χατηοδε ραψ τυβε δισπλαψσ (ΧΡΤσ), ασσεσσμεντ οφ τηε ηε
αλτη ανδ περφορμανχε εφφεχτσ οφ τηε ηυμαν−μαχηινε ιντερφαχε ηασ βεεν χονστρα
ινεδ βψ τιμε. Εμπηασισ ιν συχη ρεσεαρχη ηασ οφτεν χονχεντρατεδ ον τηε ΧΡΤ τερμ
ιναλσ∋ πηψσιχαλ χηαραχτεριστιχσ (ε.γ. σχρεεν λυμινοσιτψ, χηαραχτερ ρεσολυτιον,
σεατινγ ποσιτιον). Στυδιεσ οφ τηε ηεαλτη εφφεχτσ οφ τηεσε πηψσιχαλ χηαραχτερισ
τιχσ ηαϖε βεεν ινχονχλυσιϖε (Τυρνερ ανδ Καρασεκ 1984, 663).

Τηε αυτηορσ, ηοωεϖερ, εξαμινε τηε μορε γενεραλιζεδ πσψχηοσοματιχ στρεσ
σ προβλεμσ ασσοχιατεδ ωιτη χομπυτερ−μεδιατεδ ωορκ, αν αππροαχη τηατ ηασ βεεν
νεγλεχτεδ. Τηε πσψχηοσοματιχ εϖιδενχε συγγεστσ τηατ τηε εφφεχτσ αρε νοτ δυε το
τηε πηψσιχαλ χηαραχτεριστιχσ οφ ωορκστατιονσ βυτ ρατηερ αρισε φρομ τηε ∀στρε
σσ ρεσυλτινγ φρομ οπερατινγ χηαραχτεριστιχσ οφ τηε οϖεραλλ χομπυτερ σψστεμ.∀
(Τυρνερ ανδ Καρασεκ 1984, 663) Οπερατινγ χηαραχτεριστιχσ αρε δεφινεδ βψ τηε αυ
τηορσ το βε τηε σεθυενχεσ οφ χομμανδσ περφορμεδ βψ τηε ηυμαν αχτορ ιν ορδερ το
χοντρολ τηε σψστεμ ανδ τηε φεεδβαχκ προϖιδεδ βψ τηε σψστεμ.

Τηε μαιν οβφεχτιϖε οφ Τυρνερ ανδ Καρασεκ∋σ εφφορτσ λιεσ ιν στρυχτυρινγ
τηε ρελεϖαντ φινδινγσ ιντο υσεφυλ μοδελσ φορ χομπυτερ αππλιχατιον δεσιγνερσ. Τ
ηειρ μαιν ηψποτηεσισ ισ τηατ τασκ χηαραχτεριστιχσ ∀ιντερϖενε βετωεεν χομπυτερ
αππλιχατιον σψστεμ δεσιγν παραμετερσ∀ (Τυρνερ ανδ Καρασεκ 1984, 664) ανδ οπε
ρατορ ουτχομεσ. Τηατ ισ, τηε ιμπλεμεντατιον οφ α ηυμαν−μαχηινε ιντερφαχε χηαν
γεσ τηε διϖισιον ανδ χηαραχτερ οφ λαβουρ φορ βοτη ηυμαν ανδ μαχηινε. Α φυνχτι
οναλ σψστεμ ισ τηεν χρεατεδ τηρουγη τηε ρειντεγρατιον οφ τασκσ, οφτεν αχχομπλισ
ηεδ βψ γιϖινγ τηε οπερατορ χοντρολ σεθυενχεσ ανδ σψστεμ στατε ινφορματιον νεεδ
εδ το χομπλετε τηε τασκ. Τηεσε εφφεχτσ οφτεν οχχυρ υνιντεντιοναλλψ ον τηε παρτ
οφ τηε σψστεμ δεσιγνερσ.

Το συβσταντιατε τηειρ ποσιτιον, Τυρνερ ανδ Καρασεκ τρψ το φοργε α λινκ β
ετωεεν τηε (ι) τασκ χηαραχτεριστιχσ τηατ χουλδ αφφεχτ τηε ωελλ−βεινγ ανδ περφορ
μανχε εφφεχτιϖενεσσ οφ ηυμαν αχτορσ, ανδ (ιι) χομπυτερ αππλιχατιον δεσιγν παρα
μετερσ ωηιχη χουλδ αφφεχτ τασκ χηαραχτεριστιχσ. Εμπιριχαλ εϖιδενχε λινκινγ τηε

σε τωο σετσ οφ παραμετερσ ισ αλσο ρεϖιεωεδ.

Φιρστ, τηε αυτηορσ ρεϖιεω τασκ χηαραχτεριστιχσ ανδ ωορκερ ουτχομεσ, χα
λλινγ υπον ρελεϖαντ λιτερατυρε ιν τηε φιελδσ οφ λεαρνινγ εφφεχτιϖενεσσ, ινφορματ
ιον προχεσσινγ, ανδ οχχυπατιοναλ στρεσσ. Τηισ ματεριαλ ισ υσεδ το ιλλυστρατε η
οω τηε πσψχηοσοχιαλ στρυχτυρε οφ α τασκ αφφεχτσ τηε περφορμανχε ανδ ωελλ–βει
νγ οφ αν οπερατορ. Ωε βριεφλψ ρεϖιεω τηε ασσοχιατιονσ τηατ αρε ρελεϖαντ το ουρ
παπερ ιν τηε φολλοωινγ συβσεχτιονσ.

Οπερατορ αυτονομψ, λεαρνινγ εφφεχτιϖενεσσ, ανδ χοντρολ στρατεγιεσ. Τηε οπερατ
ορ∋σ φρεεδομ ιν σελεχτινγ αν οπερατινγ στρατεγψ ισ φουνδ το ινχρεασε λεαρνινγ εφφ
εχτιϖενεσσ (Τυρνερ ανδ Καρασεκ 1984, 666). Μορεοϖερ, ιν τηε μοστ εφφεχτιϖε χοντ
ρολ οπερατιονσ, τηε οπερατορ ηασ συφφιχιεντ κνοωλεδγε οφ σψστεμ φυνχτιοναλιτψ
ανδ ενϖιρονμενταλ χονστραιντσ το βε αβλε το ∀πρεδιχτ τηε φυτυρε στατε οφ τηε σψ
στεμ ανδ, τηυσ, υσε οπεν−λοοπ στρατεγιεσ.∀ (Τυρνερ ανδ Καρασεκ 1984, 667) Ηοωε
ϖερ, οπεν−λοοπ στρατεγιεσ αρε δισχαρδεδ φορ λεσσ εφφεχτιϖε χλοσεδ−λοοπ στρατεγ
ιεσ ασ χογνιτιϖε ωορκλοαδ ινχρεασεσ. Ιντερφαχε δεσιγνσ χαν αλσο ινηιβιτ τηε υσε
οφ οπεν−λοοπ στρατεγιεσ ∀βψ ιναδϖερτεντλψ πλαχινγ ιμπορταντ λιμιτατιονσ ον ∋δε
γρεεσ οφ φρεεδομ∋ οφ αχτιον αϖαιλαβλε το αν οπερατορ∀ (Τυρνερ ανδ Καρασεκ 198
4, 667) ανδ τηυσ λιμιτινγ σκιλλ υσαγε.

Το συμμαριζε, Τυρνερ ανδ Καρασεκ φινδ τηατ οπερατορσ

neither learn individual tasks effectively, nor are able to build a clear model of overall system functioning without autonomy to alter control strategies. Without a clear conceptual model of a system an operator is unable to employ effective feedforward predictive strategies associated with effective performance. In the stress literature, lack of control when facing heavy task demands is associated with both psychological strain and physical illness: the operator is unable to most effectively allocate his personal resources, and may also face residual strain from tasks which require arousal, but frustrate required action. (Turner and Karasek 1984, 670)
Stress consequences. The authors call upon Karasek's residual strain model in which two dimensions of the work environment define a stressful occasion: the magnitude of the cognitive load and the operator's "degree of freedom of action in the face of a demanding task." (Turner and Karasek 1984, 668) Limitations on the operator's degrees of freedom arise from the division of labour (e.g. Taylorized work) where the computer system's operating parameters are controlling factors. However, effective performance does not manifest itself in a low stress environment. The authors point out that optimal working conditions have neither too little arousal nor too much (Turner and Karasek 1984, 669), coupled with increased skill discretion.

Turner and Karasek then identify general software system parameters that may influence the psychosocial structure of a work domain. Four parameters are identified. These are:

1. Dialogue quality. The dialogue between the human and machine should provide sufficient information about the current system state and information about probable future states, all within a framework that is found to be meaningful to the operator.

2. Work flow. Work flow defines the sequence and content of tasks performed by an operator and is therefore a fundamental aspect of the division of labour.

3. System complexity. System complexity affects the human-machine division of labour as well as the ease at which the operator is able to use a mental model of the system. Complex systems have many states and thus it is often difficult to uncouple information about the internal state of a system from the content of the information provided by the interface.

4. System performance. The way a system performs affects operator performance as well. A system that fails to meet performance requirements decreases not only the effectiveness of the system, but also increases operator strain through frustration, the blocking of effective action, and so on.

Turner and Karasek then attempt to find statistically significant evidence that relates the aforementioned computer system design parameters to effects on the psychosocial conditions of the operator. The most important findings come from a study which found that clerks using computer systems reported significantly less decision latitude and greater supervisory control than groups not using computer systems. The results are illustrated in table 1 below.

Table 1. Comparison Between Task Characteristics of Operators using Computer Systems and a Control Group* (Turner and Karasek 1984, 681)

	Work Pressure +	Workload Dissatisfaction++	Quantitative Workload-Q ++	Autonomy++	Control by Supervisor +
Clearical Workers using Computer Systems	3.40	3.20	4.00	1.10	3.00
Clerical Control Group	2.40	2.40	3.60	1.80	2.70
Scale norms	1.80	2.1	--	2.70	2.30
Significance Test Level (ANOVA)	0.01	0.01	0.01	0.01	0.01

* mean scale responses for CRT operators and controls at five work groups (adapted from Smith et al. 1981) N=about 150 CRT operators and 150 controls
+ Work Environment Scale, Form S
++ Job Demands and Worker Health Scales (Caplan et al. 1975)

The explanation for these effects is that "many application systems are rigidly programmed and do not permit deviation from a prescribed activity sequence." (Turner and Karasek 1984, 681)

In conclusion, Turner and Karasek find that the decision to implement a computer system in a work setting results in a new division of labour that produces a "different mix of tasks for the human to perform, which then affects the human's well-being and the system's overall performance." (Turner and Karasek 1984, 683) Their findings also suggest that computer systems need not affect working-life quality in an adverse manner. They recommend a number of design alternatives that may lead to a high level of working-life quality. The strongest recommendation is that operators be given more decision latitude so that they can acquire new skills, increase their job satisfaction, and increase control over their work.

3.2.12 Winners and Losers From Computerization: A Study of the Psychosocial Work Conditions and Health of Swedish State Employees

This study by Aronsson, Dallner and Aborg (1994) consisted of 1,738 Swedish state-employed computer users whose health and work environment was examined through the use of surveys. These state employees came from 37 centers and 52 administrative departments. The objective of the study was to analyze the relationship between work organization and mental/somatic health symptoms among the various user groups.

Within this study, five different kinds of video display terminal (VDT) work

groups were distinguished :
1.Data entry (DE). Information is typed in, often in a standard format. The work pace is usually quick with few interruptions. Workers in a DE environment have little opportunity for decision-making; they have a low level of control over their work.

2. Data acquisition (DA). Data are displayed on a screen with a moderate rate of data entry. Control levels over the work pace and opportunities for decision making vary.

3. Interactive communication (DE + DA). This type of work involved both data entry and acquisition. There is some degree of decision making and control over the work pace. Examples included travel agencies and insurance companies.

4. Word processing (WP). This involves text entry, text recall, keying in corrections, organizing document formats and other word processing activities. There is a wide variation among these jobs as to the control the operator has over the pace and structure of the work.

5. Programming (PROG) and Computer-aided design (CAD). These jobs involve a high level of control over the pace of work and decision making.

The measuring instruments consisted of the following variables and indices (Aronsson et al. 1994, 21):

Job Demands
Type of computer work.
Time spent at VDT.
Work load.
Degree of difficulty.
Demands on attention and concentration.
Stimulation and variation of the tasks.
Computer breakdown, system overload, and alternative tasks.

Job Control
Influence over working conditions.
Computers as assistance or means of control.
Sufficient information about computerization.

Social Support
Relations with colleagues.
Relations with management.
Cooperation with others.
Job recognition.
Opportunity for obtaining assistance with computer tasks.

Health Complaints
All the questions regarding health complaints concerned the previous 12-month period. An affirmative reply to any one of the questions in an index was counted as a "yes" response.

The psychological complaints index was based on the following five items:
Often lacking in concentration.
Often restless or tense.
Often irritated or impatient.
Often anxious, uneasy, or nervous.
Often depressed, dejected, or sad.

The stomach disorders index incorporated the following three items:
Troubled by an upset stomach.
Frequent pain in the pit of the stomach or heartburn.
Trouble on occasion by stomach pains.

The overview of the background data on the subjects is shown below in Table 2.

Table 2. Personal Characteristics of the Different Groups of VDT Users (N = 1,738) (Aronsson et al. 1994, 22)

	DE	DA	DE + DA	WP	PROG	Total
Gender F/M (%)	96/4	70/30	77/23	86/14	32/68	75/25

Age (M)	39.00	39.00	40.00	40.00	35.00	39.00
Part-Time Employment (%)	33.00	22.00	30.00	27.00	13.00	27.00
Years of Employment (%)	9.00	8.00	8.00	8.00	6.00	8.00
Years With VDT's (M)	5.50	5.00	5.00	3.50	6.00	6.00
Employed > 7 Yrs (%)	31.00	29.00	12.00	11.00	36.00	27.00
Travel Time > 45 min (%)	23.00	17.00	19.00	24.00	31.00	22.00
Children Younger Than 12 Yrs @ Home (%)	35.00	34.00	35.00	26.00	42.00	34.00

The empirical data we found to be most relevant to the thesis concerned whether computers were used as a form of assistance or a means of control. It was found that the majority of word-processing clerks and programmers, system specialists, and designers saw computers as a form of assistance (see Figure 6 below).

Figure 6. Percentage of VDT users who regard computer facilities as forms of assistance/means of control (N=1,738). (Aronsson et al. 1994, 25)

Among those who occupied the data entry group, a smaller proportion regarded the computer system as a means of assistance. Of great interest is the relationship between these findings and the fact that the greatest frequency of health complaints (45%) came from the data-entry and data acquisition groups (chi-square test: $p<0.005$, df=4).

The authors conclude that the 'losers from computerization' were found to be the "group performing repetitive, monotonous data-entry work and, to a certain extent, . . . the group involved with a combination of data entry and data acquisition." (Aronsson et al. 1994, 32) The data-entry group also contained the highest percentage of workers who felt that their work conditions were problematic with respect to stress. These conditions included lack of job control, low work content, and little social support. The 'winners from computerization' were found to be the programmers and designers. They had the distinction of being the only group to be satisfied in terms of job demands, control and social support. Their health was found to be relatively good as well.

Karasek and Therorell's demand/control model provides an empirically sound and robust system that shows us how computer-mediated work can be designed so as to reduce the negative implications associated with high strain. The clearest recommendation supported by the demand/contol model is to increase the decision latitude, i.e. degrees of freedom, of low control computer-mediated work environments. The cognitive demand associated with computerized work should exihibit 'middle of the road' quantitative demand and high qualitative demand. These characteristics usher designers down the aisles of a more humanistic realm of work organization.

3.3 Case Study in the Work-Oriented Design of Computer-Mediated Work

3.3.1 UTOPIA

UTOPIA is a Scandinavian acronym for Training, Technology, and Products from a Quality of Work Perspective (Ehn 1988, 327), an acronym that represented a research project investigating issues of design and training in computer-mediated work. This research project manifested itself within the unionized graphical design industries (e.g. text and image processing) of Sweden, Denmark, Finland and Norway and took place at the Swedish Center for Working Life, The Royal Institute of Technology, Stockholm; and at Aarhus University in Denmark. On average, fifteen people took part in this project over four years with the project's inception being in 1981.

The purpose of UTOPIA was to "design computer support and professional education for integrated text and image processing." (Ehn 1988, 330) Furthermore, the design was founded upon the principles of quality of work and products, and democracy at work. The researchers involved with the project investigated issues affecting a democratic design process. Namely, they analyzed social, political, technological, and methodological limits to design of skill-enhancing computer artifacts. Ultimately, they had the end-user of these artifacts in mind.

Design workshops were developed to facilitate the acquisition of requirement specifications for a computer-based page-makeup and image processing system. The set of requirements contained "musts and ought-to's . . . to be answered." (Ehn 1988, 339) The requirement specifications also contained descriptions for work procedures, display screens, human-computer interaction, and operations for page make-up and image processing equipment. Most importantly, technical requirements were derived from the principle that the equipment should serve as a tool for skilled work. Work organization, work environment, and training specifications were also contained within this set of requirements.

Issues concerning the structure of work organization were central to UTOPIA. The researchers identified three paradigms of work organization within newspaper production. These three approaches can be classified as the traditional way, the American way, and the Scandinavian way.

The traditional way was deemed unacceptable as it did not exploit the technical possibilities afforded by new technology. This newer technology could produce finished products of higher quality as well as increase production flexibility (i.e. deadline extension). Additionally, this approach also suffered from the fact that it did not allow cooperation between graphic workers and editorial staff.

The American way, as exemplified by Star News in Los Angeles, was also deemed unacceptable because the graphic workers were eliminated from the organization. The duties of the skilled graphic workers were taken on by editorial staff. The editorial staff, facing tighter deadlines and lacking the skill of the graphic workers, were unable to maintain a desirable level of graphic creativity.

The Scandinavian way, which was supported by the UTOPIA project, called for a central production area where graphics workers (using the new technology) and editorial staff could work in a collaborative environment while maintaining a division of responsibility. As well, the Scandinavian approach recommended that

> Work should be designed so as to provide the employee with an opportunity of influencing and varying the pace of work and the working methods used, and of surveying and verifying the results of his or her labors. A shift from rigid and monotonous working procedures towards greater independence and greater vocational responsibility is essential . . . (Gunnarsson 1984)

UTOPIA developed the computer text and image processing system as a tool for the graphic worker by allowing these individuals to employ the skills and knowledge they had acquired through apprenticeship and other traditional forms of work. Through utilization of this tool-perspective, the decision latitude of graphical workers was enhanced because the computer allowed the operators to experiment with many different design and layout alternatives without committing to a specific one (Ehn 1988, 346). The operators could then use their expertise to decide which of the alternatives improved product quality the most. Consequently, these additional degrees of freedom permitted enhancement of their skills; workers could creatively explore the system facilitating the acquisition of new skills through experimentation. This can be contrasted with the systems used at Star News: editorial staff imported the text and image files which were subsequently manipulated by a computer algorithm into an 'efficient' layout. Efficient layouts are neither necessary nor sufficient to guarantee a quality product -- the tacit skill of the graphic workers could not be formalized in such a manner.

With respect to issues of training, UTOPIA's approach to work organization required the coupling of traditional artistic instruction with further instruction in the technical aspects of the computer system's use. On the other hand, the American approach did away with training for the graphical worker -- they were laid off. The training of the editorial staff in this situation consisted of rudimentary training in the use of the text and image processing software as layout was determined by an algorithmic process.

To conclude, the strategy behind UTOPIA came close to coupling the practical understanding of graphic workers with a theoretical technical-scientific knowledge that was incorporated into their computer-mediated work (Ehn 1988, 464). As well, the cherished values of workplace democracy and quality of work were upheld in a computerized work setting. By approaching workplace design with a tool-perspective, the researchers of UTOPIA were able to counter the notion that computer interfaces "would restrict the ways in which users could apply their electronic tools." (Day 1991, 93) Instead, these tools enhanced the workers' skills, knowledge, product quality, and quality of working life.

3.4 Other Case Studies in Computer-Mediated Work

3.4.1 A Study of Blue Collar Workers in Germany: Human-Computer Interaction and Implications for Stress and Performance

Michael Frese postulates that in order for a human actor to have control, she must have influence over conditions and actions at her workplace. Influence, in Frese's eyes, is the ability to choose goals, plans and the type of feedback utilized (Frese 1987, 43). The author states that without the freedom to influence, the human actor has no decision latitude and hence no control over her work.

Possibilities for decision making appear in areas of action sequencing, timeframe, and content. Action sequencing refers to the ability to order tasks, order the formation and execution of plans, and order the signals on which the operator calls to inform herself of the success or failure of her activities. Control over the timeframe of a task allows the worker to determine when the task is done or plan is formed and the length of time these activities will require (Frese 1987, 44). Content refers to the substance of decisions with regard to which task is executed, which plan is formed, and which signal or conditions to choose.

Frese (1987) identifies four prerequisites for control. The first prerequisite is skill. One needs knowledge and skill to be able to proceed towards a goal given that one has the flexibility to utilize differing plans of action. The second prerequisite is functionality. This refers to the ability of the computer system to allow and enhance completion of the workers' tasks. For example, a statistical analysis package should be able to accurately calculate and "do what it is supposed to do." (Frese 1987, 45) If a system lacks functionality, then there can be no control as the worker's actions will be unrelated to the task at hand. However, high functionality is not a sufficient condition for control. Transparency is the third prerequisite. This implies that the system should allow the worker to develop a consistent mental model of the work domain. The last prerequisite is predictability. The operator should be able to predict the system's behaviour. That is, knowing what will result from a command and when a command will be executed and completed. Lack of predictability makes decisions meaningless because the operator will not foresee future states and therefore will be unable to make proper decisions in the current state.

Control could have a direct effect on the stressors or it may act as a mediator of the relationship between stressors and stress reactions. This has been investigated in various field studies, such as those found in the section on social epidemiology. Stressors under situations lacking control often result in the worker feeling helpless and in the creation of negative physiological effects. Stress in control situations sometimes leads to heart attacks and psychosomatic complaints (Frese 1987, 46).

Regarding performance effects and potential control, Frese tells of a study conducted by Glass and Singer (1972):

In this series of experiments the subjects had a button that could turn off a loud noise (the stressor). In one condition, the subjects were asked not to use this button (and all of them complied). This condition produced less performance decrements in various tasks than not having such a control button. (Frese 1987, 46)

Performance decrements because of situations lacking control may be due to the following factors:

Helplessness. People become passive and do not explore the system.

Reactance Effects. People will try to regain control thus losing focus and neglect the task at hand.

Diffusion of Responsibility. People do not feel responsible when they are not in control and thus will not take ownership of the situation.

Reduction in Learning. When an individual is not in control, the feedback displayed

by the system is not perceived as brought about by one's own actions and therefore one does not learn from the feedback.
Fitting. Once a person is in control they can fit work conditions to their own psychophysiological requirements thus making it easier to perform their tasks.

Frese was interested in determining whether new computer technology introduced into the workplace would affect issues of control. Data outlining the opinions of blue collar workers (in Germany) towards their work had already been obtained before computers were introduced and, therefore, the experimenters decided to use this group of subjects in their study. Within this group, four subgroups could be identified. The first group consisted of those people who worked with a computer but did not program them (N=18). The second group consisted of those who worked with a computer and had some influence on programming it (N=17). The third group was made up of those people who actually programmed the computers (N=10), and finally the last group worked with robots (N=9). Information on control was collected through a questionnaire which determined how much influence the workers had on choice, sequence and so on.

Results from the questionnaire showed that group 3 had the most control at work, while group 4 had the least. Results also showed that no control was gained or lost with the transition to the new computer technology.

Researchers were also concerned with the issue of participation: do workers have a say in the process of introducing new technology (which affects how their work is done) into the workplace? Results showed (Frese 1987, 48) that:

1. Those who participate in the introduction of new technology feel that their work situation has improved ($r=0.31$, $p<0.05$, $N=53$).

2. Control over the introduction of new technology is inversely related to psychological dysfunctioning, with anxiety ($r=-0.24$, $p<0.05$, $N=56$) and marginally related with psychosomatic complaints ($r=-0.21$, $p=0.06$, $N=55$).

3. There is a high correlation between job satisfaction and the ability to control the introduction of new computer technology ($r=0.41$, $p<0.01$, $N=56$).

4. People who believe to have control over the introduction of new technology feel they have better social support from their supervisor ($r=0.30$, $p<0.05$, $N=56$).

Frese also investigated how training was affected by control. To do this, two groups were established. One group had no control over their work. They were given rule-based procedures to solve certain problems. The other group had control over the computer system and were allowed to explore the environment and develop their mental models. It was discovered that the second group was superior to the first group in various performance variables after their training session.

To conclude, Frese's studies imply that

to have control over technological changes may have positive effects on workers' psychological functioning, on job satisfaction, on a decrease of anxiety, and on a seeing the job to be better. (Frese 1987, 48)

Further, it is important to realize that control has a large effect on training. When workers are given the freedom to explore the system and develop an internalized mental model, they perform better than they would in situations of non-control with rule-based procedures to follow. Transfer of training to everyday work also increases in situations of control. Frese discovered that

Even when people learned a lot in training, they would only apply this knowledge if they had a high level of control at work; otherwise reactance and helplessness effects would decrease their motivation to use the new system in their everyday work. (Frese 1987, 49)

Finally, it can be said that it would be a useless course of action to invest in extensive and costly training for workers if an organization does not compliment this with providing a "sufficiently high degree of control to their workers" (Frese 1987, 49).

3.4.2 Finnish Flexible Manufacturing System Case Study

This case study arises from the psychological studies tendered by Vartiainen, Tiitnen and Teikeri (1991). Their goal was to study a flexible manufacturing system, its computer interfaces, and the job content of the FMS operators, and then identify which factors hindered the productivity and 'well-being' of these human actors. Vartiainen et al. define well-being in the context of working life to be "job satisfaction, [and] proper mental load" (Vartiainen et al. 1991, 38). They reject the traditional approach of concentrating on human-machine interface design and instead attempt a "holistic analysis of work activities, in which machines with or without programs are used as tools." (Vartiainen et al. 1991, 36) This approach, which views work primarily as tool-mediated activity, falls in the domain of human activity theory (see Bannon and Bodker 1991; Bodker 1991). Briefly, this theory takes "its starting point in human activity as the basic component in purposeful human work." (Bannon and Bodker 1991) Human activity is seen as being teleological in nature. It is this goal-directed activity which is usually mediated by artifacts, or tools (Figure 7).

Figure 7. Human activity is mediated by psychological or concrete tools.

Vartiainen et al. thus recognize the existence of a broader context within which work activity is enfolded: human-machine interaction occurs "in a certain organizational and physical environment." (Vartiainen et al. 1991, 36)

Three barriers to the design of a flexible domain are identified. These are the organizational, psychological, and technological barriers. The organizational barrier is seen as being principally a result of the Taylorist division of labour. To counter the absence of thinking demands found in such organizations, a necessary prerequisite for a flexible production system is the implementation of "multi-skilled and motivated personnel possessing the ability to think and solve problems independently." (Vartiainen et al. 1991, 37) That is, the workers must be given a great degree of problem solving responsibility, or decision latitude, to be able to participate effectively in the organization. As well, the employee selection process must only consider those individuals who want to think flexibly and participate in a responsible work environment.

The psychological barrier arises as a consequence of the organizational barrier. Vartiainen et al. state that the fragmented task structure of Taylorized work organizations obstruct the realization of basic psychological mechanisms -- mental regulation of work activity is restricted in terms of the shifting between different levels of cognitive control. The authors call this phenomenon hierarchically incomplete mental regulation[6] (Vartiainen et al. 1991, 37). Sequential incompleteness is also found in fragmented work. To be sequentially complete, work must include "goal-setting, planning, action programs [and] autonomous decision making . . . executing, checking and organizing." (Vartiainen et al. 1991, 37) Work, then, should

[6]There is a close relationship between the concept of hierarchical mental regulation and Rasmussen's three levels of cognitive control as described in the SRK taxonomy. For instance, the authors state that to be hierarchically complete, there "should be demands on various levels of regulation, i.e. real information processing including non-algorithmic intellectual demands." (Vartiainen et al. 1991, 37)

be both hierarchically and sequentially complete. For an interface to support hierarchically complete work, it seems that SBB, RBB, and KBB should be supported. By allowing the FMS operators to have increased responsibility for the sequential aspects of the job at hand, their decision latitude is also widened. As well, Vartiainen et al. recommend that the interface system provide "information on the current status of things and what is possible." (Vartiainen et al. 1991, 37) "What is possible" is given by the possibilities for action, the affordances of the environment in question. It seems that the researchers believe that feedback provided by the interface should be richer than in traditional FMS designs.

The last barrier identified by the authors is the technological barrier. This barrier "is the traditional allocation of functions between man and machine/program when designing tools (programs, machines, technological systems and their interfaces)." (Vartiainen et al. 1991, 38) Flexible systems require new types of computer tools that can extend sensory and motor abilities and are part of a design that incorporates complete work activities, i.e. non-fragmented work that supports hierarchical and sequential completeness.

The actual case study involves two shifts of FMS operators (N=12) at a newly built (spring 1988) production facility. The investigation consisted of the following four steps:

Formulation of system component and interface descriptions.
Interview of system specialists and system operators
Analysis of formal interactive structure of operating system (dialogue structure).
Dispensation of questionnaires to FMS operators (N=10). The questions concerned
time used in different activities by employees when operating the machinery,
error feedback and help given by software, and
general satisfaction of users with usability, flexibility, and so on.

Each question was answered using a five step scale (1=very bad . . . 5=very good).

Upon start up of this pneumatic actuator manufacturing system, the human actors were extensively trained. The plant personnel made numerous visits to other FMS-based organizations, they went to lectures, trained on a simulator several times and "were practically trained to use flexible manufacturing systems in a separate training center." (Vartiainen et al. 1991, 39) The authors note that up to "seven percent of the working time in 1989 was used for training." (Vartiainen et al. 1991, 39)

The flexible manufacturing system was controlled by a three level control system, whose structure is shown below in Figure 8.

Figure 8. Three levels of the FMS control system (PPS = Production Planning System, CAP = Computer Aided Planning, PS = Production Control, TMS = Tool Maintenance System, NC = Numerically Controlled Machine, VCS = Quality/Variance Control System). Adapted from Vartiainen et al. 1991, 40.

As can be seen in the figure above, the bottom level consists of machine tool and automated control systems. The middle level consists of a process control system (PCS) which controls the flow of components for manufacture as well as communicating with the bottom level. The top level is comprised of an operative control system (OCS) which, in turn, is connected to a production planning system.

The human actors control the OCS through the use of five computer terminals. The PCS is operated through these five terminals as well, but two other terminals with process control keyboards are also used. At the bottom level, each individual machine has its own control system that can be operated independently of the OCS.

The programs and interfaces used in the system can be divided into the following five groups: menu-based OCS programs; menu-based PCS programs; numerically controlled (NC) machining centers consisting of a screen, menu keys, and operating pad; menu-driven GUI-based tool maintenance system (TMS), and a quality/variance control system consisting of a screen, keyboard, keys and indicator lights, and a separate control unit. These five interfaces were quite different in terms of their screen layout. The complexity and inflexibility of these interfaces impacted effective use by the FMS operators.

The results of the questionnaire indicated that there were a number of problems associated with the complexity and consistency of the interfaces (Vartiainen et al. 1991, 41). Inexperienced users, which the researchers classified as 'novices', claimed that the interfaces were unreliable, hard to use, and error prone. The more experienced users, classified as 'experts', found the interfaces to possess the opposite qualities. The emergence of these two groups, experts and novices, was surprising to Vartiainen et al. "because it contrasted with the organizational aim . . . to organize jobs as group work." (Vartiainen et al. 1991, 44) The authors surmise that this division is related to the complexity level of the interface structure. Indeed, even though the human actors had the same levels of intensive basic training, "the inherent properties and structure of different interfaces were too problematic for some of the operators. This resulted in the emergence of the two sub-groups." (Vartiainen et al. 1991, 45)

The researchers identified inconsistency in the physical layout and in the human-computer interaction as being particularly problematic. Vartiainen et al., in discussing these findings, conclude that

not only design of the systems but also their implementation must be done in a wider context, taking into account organizational, training and software matters. Computer-aided-manufacturing is only a tool. Inconsistent and complicated interfaces may . . . be the result of old, Tayloristic approaches to work division. More importantly, the inconsistent interfaces may conserve the traditional organizational structure: they may be hindrances to achieving more flexible structures. (Vartiainen et al. 1991, 45)

To conclude, it seems that the traditional approach to interface design, one that is grounded in the principles of supporting Taylorized work, had an undesirable impact on the goal of implementing a flexible work organization. The interfaces structured certain aspects of the FMS operators' work. Consequently, if new forms of work organization are to succeed in computer-mediated environments, the implications of the interface design framework used must be congruent with the workplace values sought in the organization. In the case of this FMS plant, further success might have been achieved if the interfaces supported hierarchically and sequentially complete work.

3.4.3 ESPRIT PROJECT 1217(1199)

Project 1217(1199), entitled "Human-Centred Computer Integrated Manufacturing (CIM) Systems", was a European Economic Community (EEC) project under the auspices of the ESPRIT programme. The EEC funded this project with £5,000,000 over the three years starting in 1986 and ending in 1989. This multidisciplinary project consisted of three national design groups, each from the United Kingdom, Denmark, and West Germany.

This was a key project in the development of human-centred CIM. Essentially, a human-centred design approach designs technology and work organization around and for the worker. The worker is seen as an important asset in the organization. Hence, the knowledge, capabilities, experience and creativity of the workers are exploited to their fullest potential while increasing the quality of the workers' decision latitude, social support, and cognitive demands. Control and responsibility over the work process is given to the worker. An important ingredient in human-centred computer-mediated work is the dispensation of appropriate computerized support to ensure that the workers' skills are not underutilized. To be sure, this support aims to enhance their skills by allowing them to employ experience based knowledge (Corbett et al. 1991).

The main objectives of the project (Hancke et al. 1989) were:
to establish criteria for the design of human-centred CIM,
to develop a highly flexible manufacturing system that provides a better work environment,
to develop training practices for multi-skilled workers, and
to exhibit the economic and commercial competitiveness of a CIM design that utilizes the human-centred concept.

Two production cells were developed: a computer numerical control (CNC) turning cell with two lathes at Rolls Royce, and a product-oriented production island at BICC Sealectro.

The CNC control software design was based on the principle of shop-floor programming. Succinctly put, shop-floor programming methods allow the skilled workers on the shop floor to have control over numerical control (NC) programming for processes such as "turning, milling, grinding, and sheet-metal work." (Brodner 1990, 105) This approach can be contrasted with the traditional programming and editing techniques that ignore the way skilled workers think and work. Instead of relying on the skilled workers' practical experience, the traditional programming methods are abstract and algorithmic in nature as they emanate from the realms of engineering and data processing (Brodner 1990).

Of primary interest to this thesis was the project's important aim of ensuring that the computer interface did not constrain the machine operators' degrees of freedom with respect to useful operating strategies. As Corbett et al. point out, it is crucial that "[o]perators should have the freedom to shift strategies without losing software support." (Corbett et al. 1991, 72) Thus, tasks that exhibit choice uncertainty are acknowledged to exist and as a consequence the human actor is enabled to use her skills and tacit knowledge to avoid or correct any errors.

Three groups of criteria for human-centered human-machine interface design were established. These criteria stressed one of the following three strategies (Corbett et al. 1991):
1. Flexible allocation of functions between human and machine.
2. The possibility of an 'overall' view of the process.
3. An 'open' software design allowing the worker to follow her own preferred work strategies.
These criteria are described below.

<u>1. Flexible allocation of functions between human and machine.</u>
This first set of criteria were achieved through the use of the principles of complementarity, operator control, and interactivity.

Complementarity. The human-machine system should be designed so that the routine and repetitive tasks are allocated to the computer while those that require skill, creativity, and decision making are allocated to the human.

Operator control. The human actor should have the freedom to choose how those tasks that can be performed either by her or automatically by the machine are divided between the operator and computer system. This flexible allocation of tasks allows for a multiplicity of users, a great degree of flexibility and the opportunity for the user to learn machining skills at a pace consonant with her abilities.

Interactivity. The software should provide an interaction style that is dependent on the task at hand. For example, if the task is routine and somewhat automated, an interactive screen editor will suffice. On the other hand, if the task is open to some disturbance, the software should be operator controlled.

2. The possibility of an 'overall' view of the process.
The second set of criteria were achieved through use of the principles of minimum shock, transparency, compatibility, and accountability.

Minimum Shock. This principle stipulates that the system should not do anything that the operator finds unexpected in light of her knowledge of the current system state.
Transparency. The operator must be able to see the internal processes of the system in order to control it effectively. Effective control of a process is facilitated by attaining an understanding of the system's operation.

Compatibility. It is important that the operator enters and receives information compatible with her training so that the system interface is structurally coherent.

Accountability. The operator should know what the software is doing. Consequently, the software architecture must be self-describing, e.g. through the use of an integrated 'help' system.
3. An 'open' software design allowing the worker to follow her own preferred work strategies.

The last set of criteria were achieved through fidelity to the principles of operating flexibility, disturbance control, fallibility and error reversibility.

Operating Flexibility. This criterion stipulates that the operators should have increased strategic degrees of freedom without loss of software support, i.e. the interface should allow the operator to shift control strategies with minimal constraints.

Disturbance Control. As software cannot predict all possible disturbances in a complex technological system, the operator should be provided with control and software support in these situations. This is based on the fact that operators are able to cope with unforeseen events.

Fallibility. Support for tacit knowledge and skill should be designed into the system. The operator should never be put in a position where she looks on helplessly as the computer carries out an incorrect operation that she had foreseen.

Error Reversibility. In learning environments, trial and error is often a component of the exploration of alternative ways of doing. Errors in machining can be costly and "all but the mostly highly skilled machinists are . . . not prepared to risk full exploration." (Corbett et al. 1991, 74) To minimize such risk, the software should supply information to the operator in a feedforward manner to inform her of the possible consequences of her actions.

For the implementation of the CIM software support to be successful, the principles of the work organization were made congruent with the principles underlying the flexibility and autonomy of the operator's job. In a paper entitled "Human-Centred Computer Integrated Manufacturing," Symon illustrates this congruency:

> . . . to be successful, this operator control and autonomy must also be reflected . . . in a change in working practices. Consequently, members of the Rolls Royce steering group suggested modifying the 'operations sheet' which details the exact sequence of operations to be followed to manufacture a part. ESPRIT machine operators simply receive a diagram of the part and no instructions, so that their own judgement and skill determines the best method of manufacture. (Symon 1990, 226)

How successful was Project 1217(1199)? A preliminary benefit analysis was

performed by BICC for its Sealectro production cell (Hancke et al. 1989). BICC's business objectives included:
improvement of customer due date performance,
reduction of manufacturing lead time,
reduction of working capital, and
reduction of operating expenses

A simulation of the Sealectro human-centered CIM production island was performed over a period of 13 weeks and the results were compared with actual performance data from an existing technocentric production island. The personnel and machine resources were the same for both production islands. The order volume, a continuous raw material flow, and small batch production were the same as well. The following results (see Table 3 and Table 4 below) were obtained (Hancke et al. 1989).

Table 3. Due date performance increased by 55% for the Human-Centered Island (Hancke et al. 1989).

	Early	On Time	Late
Existing Island	18%	31%	51%
Simulation	14%	86%	0%

Table 4. Reduction of lead time is indicated in the reduction of the average work in-progress levels, expressed in Weeks of Sales. Lead time was halved, while throughput was doubled in the Human-Centered Island (Hancke et al. 1989).

	Weeks of Sales
Existing Island	2.45
Simulation	1.12

Additionally, the reduction of working capital was realized through a 45% reduction in the overall average work in-progress. Operating expenses were reduced with a 75% reduction in excess working hours (Hancke et al. 1989).

The final report of the ESPRIT 1217 project by BICC Technologies nicely summarizes the commercial advantages of human-centred systems:

BICC Technologies has observed that for many small-to-medium sized enterprises, the traditional approach to improving manufacturing performance of increasing automation and controlling the organization through a central computer system has not yielded the anticipated improvements in the commercial performance of the enterprise as a whole. This is particularly true where the enterprise is operating in a highly volatile or specialised market sector and cannot therefore exploit the benefits of economies of scale.

Thus where increased flexibility and responsiveness to perturbations is necessary to ensure competitiveness in the market place, it has been demonstrated that an organisation and computer systems strategy designed to enhance rather than eradicate the capability of the people in the organisation will be more robust and beneficial. (Hamlin cited in IAM 1990, 17)

In summary, the ESPRIT 1217(1199) computer software interfaces were instrumental in supporting the notion of the 'computer-aided craftsperson', a class of worker whose experience and skills are enhanced through the use of computerized tools. The software was specifically developed to support increased decision latitude; the workers were encouraged to explore and execute different manufacturing strategies. Indeed, the interface designs supported not only increased strategic degrees of freedom, but also skill-based behaviour. The project personnel also implemented a training methodology that maintained a strong level of consistency with the type of work afforded by the interface. The combination of these human-centred design principles resulted in an improved production island, both in terms of efficiency and quality of work.

Chapter 4: Conclusion and Recommendations

The objective of this thesis has been an examination of a particular human factors framework, ecological interface design, through an extensive review of empirical investigations and case studies in computer-mediated work. We have attempted to causally link the theoretical implications of EID to implications for working life. We will now examine what we have learned about EID's three theoretical implications. Though we cannot formulate a comprehensive theory of the social effects of EID, we can use the case-studies and empirical evidence as paradigms or models to draw robust conclusions.

Under the rubric of decision latitude we have uncovered conclusive evidence that the increased degrees of freedom provided by ecological interface design are a necessary precondition for a healthy and high quality working life. These findings are based on an extensive body of empirical evidence arising from Karasek and Theorell's (1990) investigations. The total number of studies investigated by Karasek and Theorell approach a figure at least an order of magnitude greater than the twelve studies presented in section 3.2. The total number of subjects used in their statistical analyses approaches a figure in the range of a hundred thousand. Additionally, the UTOPIA research project, the Study of Blue Collar Workers in Germany, the Finnish FMS Study, and ESPRIT Project 1217(1199) point to the instrumental nature of software interfaces in supporting a high quality of working life through increased strategic degrees of freedom. Therefore, the human actor must not only have these increased degrees of freedom made available, but must, out of necessity, be empowered to effectively exploit the available degrees of freedom. As a comprehensive framework that requires more problem solving responsibility in a work domain, EID is an effective tool that can be used to realize this goal.

Training issues are necessarily impacted as a result of the above discussion concerning decision latitude. A number of the case studies exhibited a training philosophy congruent with EID's implications for training: to effectively use an EID interface, people must be flexible and adaptive thinkers. UTOPIA's approach to work organization required a training philosophy wherein the graphical workers were instructed both in technical and artistic aspects of computer system use. This approach emphasized flexible and adaptive thinking. ESPRIT Project 1217(1199) displayed a similar approach to training: machine operators were weaned away from a rigid, proceduralized 'operations sheet' and taught how to think functionally and responsibly on their own. It is important, then, for an organization to implement a training philosophy that instructs workers how to think flexibly and adaptively in an environment where they have a high degree of autonomy. Through such instruction workers will be able to skillfully cope with their increased degrees of freedom and thus become enabled to participate effectively in the work domain.

Due to the fact that an interface based on the principles of EID provides rich perceptual feedback it enables the human actor to take in this feedback and ultimately learn from it. The new knowledge gained from this feedback helps the operator acquire new skills and also helps maintain the skills they have already developed. Most importantly, this feedback helps to ensure that a deskilling effect does not take place. Researchers involved with the UTOPIA Project were successful at ensuring that deskilling did not take place by designing an interface which allowed the graphical design workers to explore the system, receive feedback from their inquiries, and, as a result, enhance their skills through exploration. ESPRIT Project 1217(1199) also considered this issue of deskilling. An important aspect in human-centred computer-mediated work is the allocation of appropriate computerized support to ensure that the human actor's skills are fully exploited. As such, this support tries to enhance worker skills by forcing them to employ experience-based knowledge. Wicken's argument does not play any significant role in these field studies as rich perceptual feedback, coupled with increased worker autonomy, increases job content, i.e. the computer system acts as a tool for enhancing skilled performance. Also, increased job content results in a more motivated worker who has a desire to, and the capability to, reflect upon the feedback and learn from it. Laboratory studies cannot provide the same level of motivation as many subjects are not as deeply involved as a worker in an operational setting would be. Deskilling in a work situation that is replete with increased strategic degrees of freedom and rich perceptual feedback would most likely be a result of an improper approach to training -- analytical and skill-based behaviour must be addressed by the training program.

The case studies, the Finnish FMS Study in particular, have shown us that designers must have a sensitivity to the effects of work organization. The computer system interface's implications must be congruent with the work organization's goals in order to be truly effective. In the Finnish study, the researchers believed that the interface designs used in the FMS plant reflected principles that were grounded in Taylorized work. This had an undesirable impact on the implementation of the flexible and high worker-control work organization. EID supports implicit design principles that are consonant with the objectives of newer forms of work organization such as human-centred design. We believe that ecological interface design is most effective when used as an interface design framework within an organizational design that values increased decision latitude, flexible and adaptive training, and skilled enhancement through rich perceptual feedback.

In conclusion, ecological interface design seems that it would impact positively on the quality of working life given that the conditions outlined in the preceding paragraphs are met. EID can be a 'good thing'. There are important implications for high-control environments such as process control plants. Approaches to training and work allocation would have to be rethought; operators in such high-risk domains should be given more strategic degrees of freedom. Some might think that this would lead to an increased chance of system error, but we must realize that procedural rule-based approaches rely heavily upon the mistaken assumption that all events can be anticipated, which is an error in itself. This, in turn, would have implications for hiring practice in tightly-coupled complex domains: operators should have a good analytical background (e.g. engineering school graduates) as well as the capacity for skilled performance.

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