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An Experimental Evaluation of Functional Displays in Process Supervision and Control

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ABSTRACT

This report describes the work conducted this year leading to an experimental evaluation of functional displays for process supervision and control. The trend to move information for complex systems, like power plants, to computerized displays often leads to problems with loss of orientation and navigation in the display set. This report reviews the literature that documents these problems. Although adding functional information to displays has been shown to have many benefits, these displays would seem to be prone to even greater losses of integration and navigation when they are applied to large scale systems. To investigate this problem, an extensive review of ideas on navigation in both computer and natural environments was conducted. From this review, the loss of functional linking and connecting information was determined to be the area vulnerable to the most dangerous potential loss of integration. For this reason, an experiment has been proposed to investigate the effects of losing these functional connections and approaches for reinforcing these connections through interface design.

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INTRODUCTION

Traditionally, engineers have provided plant operators with low-level information, primarily sensor readings (Goodstein, 1981). However, operators can also be given information on plant goals and processes or functional information. Vicente and Rasmussen (1992) advocate the use of five levels of functional information ordered hierarchically from plant purposes to plant components. Adding these levels of functional information to process control displays has been shown to improve operator performance in small-scale systems (e.g., Pawlak & Vicente, 1996). However, as functional information is added to the displays for larger scale systems, a new set of problems will be encountered. Computer display systems for large scale systems are already plagued with problems that result from providing an operator with a large information space that is only accessible from one or a few CRTs (e.g., Roth, Mumaw, & Stubler; 1993). By increasing the information space, adding functional information would seem to magnify these problems.

The problems with large scale computer display systems are primarily problems of integration. Authors (Elm & Woods, 1985; Woods et al, 1990; Roth et. al, 1993) suggest users are getting lost in the large display systems and losing the "big picture", a sense of what is happening to the system as a whole. Computer display systems built on hierarchies of functional information would seem to be even more vulnerable to these problems. At the most obvious level, the information space available to the operator has been enlarged, increasing the scale of the display system. There is a more subtle and dangerous vulnerability though - not only does the abstraction hierarchy space provide additional information, it also provides information on the links between those functional levels. These links form the vital connections between the purposes and components of the plant. Without the links, the information at the different levels is effectively isolated, stripped of context, and difficult to use. It is these links which seem most vulnerable to deterioration as designers seek to parse and split displays in order to effectively manage a large information space on a limited hardware space.

This project proposes a study of the problems which arise as functional link information is degraded as a result of needing to supply an operator with a large information display space on a limited hardware space. It also looks at whether or not functional link information can be reinforced by interface design. Visual momentum, or a continuity of flow, has been suggested as a design goal for these interface situations. This particular research looks at one proposed design technique for supporting visual momentum specifically to reinforce those links between the different levels of functional information.

The first section of this report begins with a discussion of the benefits gained from adding functional information to interfaces. The next section details the problems that have been noted with displays for large scale systems. Most of these problems deal with the loss of integration and the resulting difficulty of navigating through these display systems. The following parts of the first section review relevant literature about navigation in both physical and computer environments.

In the second section of the report, the functional models used to determine the functional displays are discussed. Two approaches are used in a complementary fashion - those approaches being the abstraction hierarchy models of Rasmussen (1985) and the multi-level flow modeling (MFM) technique of Lind (1991a; 1991b). The benefits of each technique are discussed.

The third section of the report begins by reviewing the more significant work on evaluating multi-level functional displays. Some design solutions to counter the navigation and loss of integration problems, such as Woods' (1984) techniques for providing visual momentum, are discussed. To evaluate the success of interfaces in supporting navigation, possible measures of navigation are reviewed.

The final section of the report presents a proposal for experimentation. It is argued in this section that integration issues associated with the application of functional displays to large scale systems should be investigated. Furthermore, it is argued that the most promising place to begin this investigation is by examining the integration between functional levels since, if the connection between functional levels is lost, the benefits of the functional displays are lost as well. The second factor for investigation is whether or not a design technique proposed by Woods (1984), display overlap, can successfully improve visual momentum and navigation through the displays. It is hypothesized that this promising design technique will improve integration further. At the conclusion of this section an updated status report and revised work plan is provided.

NAVIGATION AND FUNCTIONAL INFORMATION

This section begins by discussing the benefits gained from adding functional information to interfaces. However, there are many problems with computer displays in large scale systems. These problems are discussed in the second section. Many of these problems are navigation problems. Because of the similarity with real world navigation, some background literature on navigation through physical environments has been presented in the third section. In the fourth section literature specific to navigating through computer systems has been reviewed.

The Need for Functional Information

Rasmussen (1985) found that people working on complex systems move from plant purposes to the component of interest. He found that this movement could be described as moving across 2 dimensions, one being an aggregation dimension, whole system to components, the other being a dimension of functional abstraction from functional purpose to physical form. Combined, these dimensions form a two-dimensional space of aggregation and abstraction. Traditionally, engineers have provided control room operators with only physical information, mostly sensor readings. Rasmussen's findings and ideas, however, have suggested that much could be gained by providing operators with higher level information - information on plant purposes and intermediate information linking plant purposes to components (Vicente & Rasmussen, 1992).

The initial results of following this approach have been promising. Vicente, Christoffersen, and Pereklita (1995) showed that an interface containing both physical and functional information resulted in better diagnosis performance over an interface with physical information alone. Pawlak and Vicente (1996) extended their investigation to the control task. They found that the subjects using the interface with physical and functional information detected faults more quickly and accurately and adopted more sophisticated and effective strategies. Long term studies of use of the physical and functional interface have shown similar success (Christoffersen, Hunter & Vicente, 1994; Howie, Janzen & Vicente, 1996). These studies have been of a feedwater subsystem, however, and it remains to be shown whether functional information can be added beneficially to interfaces for larger scale systems.

Problems with Navigation and Integration in Large Scale Systems

The current trend is to adopt computerized display technology for the control of complex process control systems (Roth, Mumaw, & Stubler, 1993). These systems are complex, however, so presenting the information from these systems on a few computer screens requires parsing the information into small screen-size packets. The actual information space behind the CRT can be immense. In addition, improved computational ability and graphics displays encourage the provision of more information to the operator than ever before.

Several authors have discussed the display design challenges of these new systems. Roth et al. (1993) discuss problems with getting lost, and the inability or excessively long times to access the correct display. These are all problems which occur as integration between displays is degraded. The problems with navigation through these display sets are mentioned many times (Elm & Woods, 1985; Eastman, Woods, & Elm, 1986;

Woods, Roth, Stubler, & Mumaw, 1990). Elm and Woods (1985, p. 927) have described getting lost as having three distinguishing characteristics:

1. "the user does not have a clear conception of relationships within the system"
2. "does not know his present location in the system relative to the display structure"
3. "finds it difficult to decide where to look next within the system."

Clearly, as these computer display systems become large, operators are being faced with the need to navigate through systems in much the same way that people navigate through physical environments. For example, Elm and Woods (1985, p. 927) described the demonstration of good spatial navigation skill as:

1. "the ability to generate specific routes as task demands require"
2. "the ability to traverse or generate new routes as skillfully as familiar ones"
3. "orientation abilities, that is, the development of a concept of here in relation to other places"

This description is identical to how one would describe good navigation skill in the physical world. The next section briefly reviews what is known about navigating in physical environments. Navigating in physical environments has been studied longer and more thoroughly than navigation in virtual environments. For this reason, the literature on physical navigation has been reviewed briefly to provide insight into the new navigation problems that can arise with computer displays.

Navigating in Physical Environments

As discussed in the previous section, large scale computer display systems are starting to confront operators with problems of navigation and getting lost. Elements of this problem are very similar to the problem of navigating in the physical world. For this reason, navigation in physical environments is reviewed in this section.

In its most basic form, navigation is a skill demonstrated by many animals. The basic definition of navigation is *the purposeful control of motion from place to place* (Anderson, 1983). This very basic definition highlights several important points. First there must be two places, a starting place and a finishing place. In the navigation task, the person must be able to move from place to place and furthermore must have control over that motion. Being a passenger is not navigation and being a wanderer is not navigation. It is important to remember that navigation is *purposeful*, that is, there must be intention and the behaviour must be goal-directed.

This section reviews the existing literature on navigation in physical environments. First there is a discussion of the human factors perspective on navigation through physical environments. This includes the classical psychological view which discusses the knowledge and mental models involved in successful navigation. The second perspective is a field theoretic psychological view which examines the detailed information in the environment that, when combined with the person's locomotion capabilities, makes navigation a possibility. This literature on how people navigate successfully through real environments leads to insights useful for studying navigation in the virtual environment of the computer interface.

<u>The Human Factors Perspective.</u> Wickens (1992) provides a summary of human factors work in the area of real world navigation. Landmark knowledge, or recognition of landmarks, is used to provide orientation. Route knowledge comprises directions from a person-centered frame of reference. A world-centered frame of reference requires survey knowledge. Landmark knowledge is acquired first, then route knowledge, finally survey knowledge. There are also different advantages to each type of knowledge. Route knowledge is useful in situations where the information must be communicated verbally. Survey knowledge is useful in situations where people in different locations and frames of reference must communicate.

Implementations of these knowledge types are also summarized in Wickens (1992). The map is an implementation of survey knowledge. The route list is an implementation of route knowledge. The route list is a highly efficient way of getting to a location but the map, though less efficient, can provide information that is useful if the user becomes lost.

Fixed “north-up” maps are most useful when communication between different people is required. Rotating user-oriented maps can be more efficient for single person navigation.

Chignell (1992) has provided a review of the psychological factors that may be implicated in navigation, particularly in navigation of hierarchies. The understanding that the user has of the information space, often called mental models or cognitive maps, effects their ability to navigate through it quickly and efficiently. The mental model of the user can direct the navigation and an interface can affect the mental model held by the user. An interface that reflects the structure of the system will aid the user in navigating that structure. An interface that is poorly organized and does not make relationships clear can confuse the user further.

The spatial abilities and search styles of people can have a great effect on their navigational skill. Vicente et. al (1987) found that people with strong spatial ability performed better when finding information within a hierarchy. The aspects of navigation which are visual may be affected by pattern recognition and feature detection skills. To improve navigation, people have examined the effects of training and different frames of reference of the knowledge, often referred to as “route” and “survey” knowledge. In terms of measuring navigation through hierarchies, Chignell mentions the use of recall and sorting tasks as a way to evaluate offline how well the user has understood the structure of the information. No suggestions were made on how to evaluate navigation performance online.

The Field-Theoretic Approach. There is also an approach to studying navigation that is best described as field-theoretic in origin. Noting the advances made in physics with the discovery of electromagnetic fields and their “action-at-a-distance” effect (Einstein & Infeld, 1938), some psychologists have postulated that the environment around us also has an “action-at-a-distance” effect on our actions. People are immersed in a continuous information environment that changes value with every movement and with the passage of time. This information environment, coupled with our intentions, can explain our navigation through the environment.

Many of the field-based approaches have originated from Gibson's work. The earliest example is Gibson and Crooks (1938/1982) which contains a detailed field explanation of driving behaviour and this is described in more detail in the following section. Following this early and insightful beginning, Gibson continued to elaborate his ideas, primarily in the visual perception of natural environments. His work showed that field ideas could be formalized and measured and applied in the comparison of different environments. This is the overarching challenge from the field-theoretic approach to navigation - Is it possible to describe and quantify navigation based on an intention-based description of the environment?

The next major progression in the use of field theoretic concepts in describing navigation comes from the work of Shaw, Kadar and group (Kadar, Flascher, & Shaw, 1995; Shaw, Flascher & Kadar, 1995; Turvey&Shaw, 1995; Kadar, 1996). They have moved beyond the primarily visual fields described by Gibson and explored ways of linking visual information fields with the action abilities of the observer to obtain what they have termed a conjugate field. They argue that understanding both the information field as well as the action field is necessary to completely explain purposeful movement in the environment.

Driving through an Interface?: Gibson and Crooks (1938). Gibson and Crooks (1938/1982) used the ideas of fields to describe automobile driving behaviour. They described driving as "a type of locomotion through a 'terrain' or field of space" (p. 120). They stated further that locomotion was guided primarily by vision in terms of a path within the visual field. Within the *field of space* there exists a *field of safe travel* which consists of "all paths which the car may take unimpeded" (p. 120). The important aspects of this field are that it moves through space with the car. Therefore, the point of reference for this field of safe travel, shown in Figure 1, is the driver-and-car and not some stationary point in the environment. This field is neither solely physical nor solely subjective but is a relational field relating the physical constraints of the environment with the action capabilities (such as braking effectiveness) of the person-and-car system. Gibson and Crooks continued to develop measures and definitions important to driving behaviour based on this field. The *minimum stopping zone* is an example of one of these field-based measures.

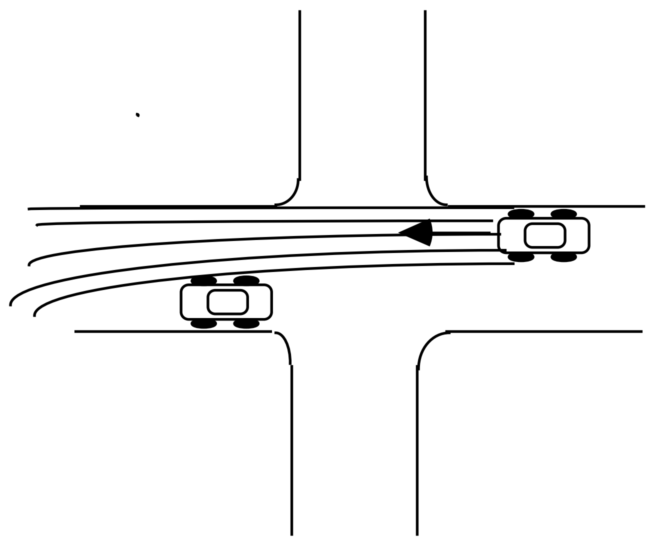


Figure 1. Gibson & Crooks' field of safe travel (1938).

There are several concepts here which are relevant. The first relevant concept is the idea of locomoting through a field of space. This is very close to the basic definition of navigation of Anderson (1983). A more exact definition would be locomoting *towards a goal* through a field of space. Simple ‘locomoting’ might describe wandering and wandering is not of interest here, but navigation! An interface provides a mediated space or field through which a user must move or locomote. But when defining the ‘field’ of interest, the important quality is that the field under study, like Gibson’s ‘field of safe travel’, is a *relational* field relating the operator’s goals to the environment. That is, the nature of the field changes with changes in the operator's intentions. Gibson and Crooks’ other measures provide guidance and examples of how potentially relevant measures may be generated from the field-based approach. The specific measures for a power plant task, obviously, would be different.

Locomoting through mediated environments: Gibson. From these early promising ideas, Gibson continued to refine and define his ideas, concentrating mostly on the visual perception of natural environments. His 1979 book contains a description of many of his ideas. Much of Gibson's work discusses the problem of locomotion. Locomotion, according to Gibson, begins with the perception of self and the perception of self in the environment. As an observer moves through an environment the information array picked up by the observer continually changes with the change in the observer's position. Despite this changing information, however, there are relations in that information which allow an observer to determine such things as destination.

Gibson further describes locomotion as visually guided and controlled by information. He differentiates between active and passive movement, passive being the case where an observer is transported but not controlling the movement. This is an important distinction which highlights the difference between locomotion and transportation.

Another important distinction that Gibson makes is the difference between perceiving a natural environment directly and perception of the environment via various mediating tools or forms. The skillful use of mediating forms preserves the information which specifies environmental events. This is the foundation of the idea of *ecological interface design* (Vicente & Rasmussen, 1990, 1992). Mediating forms, however, do not provide the complete information available from the actual event in the natural environment (Vicente & Burns, 1996).

The problem of interface design is a problem of providing mediated information on a natural system to an observer in the situation where it is not possible or practical to have the observer interacting directly with the environment. It is important then to take note of

Gibson's discussions of mediated perception. Locomotion in a mediated environment would still be visually guided and controlled by the information picked up by the observer. Gibson's discussion of the importance of control in locomotion brings up an important distinction and eliminates the selection of certain tasks for the study of locomotion. Clearly, the observer must have the ability to move throughout the environment otherwise the observer is a passenger and not a navigator. The changes in the visual information provided to the operator will be influenced by the navigational and orientation mechanisms designed into the displays. These influences must be carefully outlined and understood since, according to Gibson, these differences in the optical information will guide the locomotion. The conclusion underlying these ideas is that providing a different information environment, or different interface, will result in different locomotion even when the plant remains the same. In these terms, therefore, the goal of this study is investigate carefully which information environments will provide for improved navigation through the complex information space of a power plant displayed using physical and functional information.

Navigation Paths in Architecture: Benedikt's Isovist Fields. Benedikt (1979) used Gibson's idea that an observer is immersed in a field of light-borne information to describe architectural spaces, such as rooms and buildings. As the observer moves through the building, the visual information continually changes. He drew from Gibson's information array the concept of an *isovist* which he defines as "a location-specific pattern of visibility" (p.48). Figure 2 shows an isovist in a cluttered environment. At each vantage point in space an isovist can be defined. A path through the environment generates a changing pattern of isovists. These patterns of isovists could act as informers to navigation.

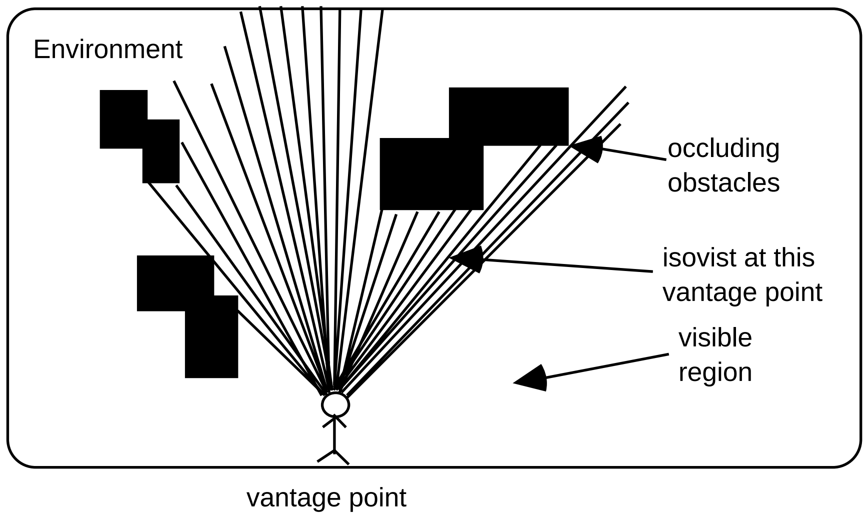


Figure 2. Benedikt's (1979) definition of isovist.

By working in architectural space, Benedikt was able to simplify his discussion to two-dimensional isovists, such as what might be worked out off of a floor plan or blueprint. Benedikt was also able to take advantage of the fact that light travels in straight lines to describe isovists analytically and to develop environment measures based on isovists.

Benedikt’s discussion of the visual environment may be useful for discussing some aspects of computer interfaces. The definition used by Benedikt of the environment as “a field of light-borne information” seems very relevant to the computer situation. It must be remembered though that the computer environment is an interface mediating between the observer and a real environment. The observer is not completely “immersed” in the interface but the degree of focus and engagement can be high.

A critical similarity though is that both natural environments and computer environments can occlude information and provide limited visibility of information (Woods et al, 1990). Woods et al (1990) described this as a *keyhole* view of the system, but it seems analogous in many ways to Benedikt’s concept of the isovist. Both are patterns of visibility and occludedness. Both are location-specific. However, the methods of changing location in a virtual environment can be quite different from in a real environment. For example, computer displays systems often present a static vista that the observer can travel throughout without changing the vista. Observers make disjoint leaps from vista to vista. Sometimes the next vista is completely invisible, or "occluded" from the previous vista. This would be the case in which the user moves from screen to screen with each subsequent screen being completely different. In the case of a zooming display the leap between vistas is not as disjoint. In "zooming in" the new vista is within the previous vista. In "zooming out" the previous vista is within the new vista. Woods' keyhole effect, therefore, can be thought of in terms of vista and isovist changes.

In summary, therefore, Benedikt's isovists have relevance for describing the environment of computerized display systems. Like isovists, computerized displays have patterns of visibility and occludedness depending on the location of the observer. In large scale systems occludedness, or the keyhole effect, has been mentioned often as a design problem (Woods et al, 1990; Roth, Mumaw, & Stubler, 1993).

<u>From passageways to PP interfaces: Shaw & Kadar & group.</u> Shaw's group has continued the effort to develop field descriptions of the environment (Kadar, Flascher, & Shaw, 1995). They have added the concept of an action field and used both information and action fields to describe navigation. Much of their work starts with the isovist field outlined by Benedikt (1979). In addition to the isovist field, they have also added a control field. The control field is the field of action capabilities, and therefore, is orthogonal to the isovist field which is the field of information. Superimposed on each other, the two fields create the *conjugate field* and the combined field is the field of perception-action possibilities.

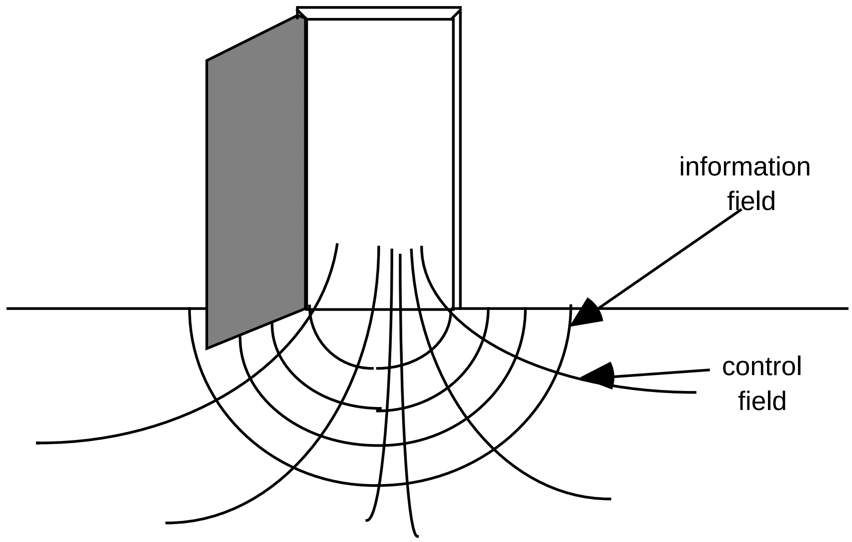


Figure 3. Information and control fields for navigating through a doorway.

To illustrate the fields, they have used the example of passing through a doorway (Figure 3). As an example, the task might be to get out of the room by the shortest path (Kadar, Shaw, Garrett, Mitra, & Flascher, draft). In this case the important information field is an iso-distance field about the door opening. The iso-distance field, like Gibson and Crooks' field of safe travel (1938), is a relational field relating the intentions of the actor to the physical characteristics of the environment. This intentionality is a critical aspect of Shaw's work (Shaw et al, draft; Shaw & Kinsella-Shaw, 1988; Shaw et al, 1990; Turvey & Shaw, 1995). The intention, or goal-directedness of the behaviour is always critical since this determines what aspects of the information field the actor will be picking up on. The iso-distance field is the field for the task of getting out by the shortest path but a different task will cause the person to pick up on a different field.

Kadar (1996) has also discussed the meaning of the conjugate field for interface design. An interface designer is responsible for making the information and the control action possibilities available to the operator. In other words, the interface designer is providing a conjugate field for the operator. Given this view, the question becomes whether or not this conjugate field can be designed in such a way as to guide the operator to achieving his or her goals. In an abstract view, one could picture creating a minimum in the field which would act as a sink pulling the operator towards the solution. This is an intriguing view of interface design.

There are several strengths to Shaw and Kadar's conjugate field approach. First it adheres most closely to the definition of navigation, that being, the purposeful control of motion from place to place (Anderson, 1983). The emphasis in this approach is on the purpose, or the intention of the navigator. When the intention is to leave the room by the shortest path, the relevant information is the iso-distance field about the exit. Understanding the intention is critical for understanding what information the navigator is picking up. This suggests the first major hurdle in applying this approach to studying interface design - what task should be studied? The task given to the subjects plants the intention and will influence what parts of the information field they use. The task must be relevant and representative of an actual process control task otherwise the information field differences obtained will not be relevant and meaningful.

A second strength of this approach is its mathematical strength. However, studying navigation through gaps provides several advantages that will not be as obviously available in a mediated environment. Two dimensional space may be used and measured with a measuring tape. What is the dimensionality of interface space and how can it be measured?

The third strength of this approach is its ability to effectively link perception and action. This brings about an implementation issue in studying interface design - to what extent must the interface be implemented in order to achieve worthwhile results? Is it sufficient to just provide screen manipulations? Or must the interface be displaying an operating plant and providing control for that plant? In any case, if the controllability has limitations, the impact of these limitations on the generalizability of the results will have to be acknowledged and discussed.

Navigating in Computer Environments

The area of human-computer interaction which has spent the most time studying navigation is the hypertext area. Hypertext results in the creation of complex information spaces that are highly cross-linked, therefore the user no longer has to proceed through the space in a linear predetermined fashion (McKnight, Dillon & Richardson, 1991). Hypertext researchers often discuss the problem of "getting lost in hyperspace" and yet there are few available studies which define and document the 'getting lost' phenomenon. Attention has been focused on developing hypertext structures (e.g. Thüring, Haake & Hanneman, 1991; Creech, Freeze & Griss, 1991) and different means of aggregating complex hypertext structures (e.g. Botofago & Schneiderman, 1991; Bernstein, Bolter, Joyce & Mylonas, 1991). The problem of navigation in hypertext is still under discussion with the exponential expansion of the World Wide Web (Cockburn & Jones, 1996).

From an empirical standpoint, however, the hypertext literature is unsatisfying (Hypertext '91; Hypertext '93 are examples). The 'navigation problem' is mentioned repeatedly but dealt with rarely. It is undocumented, undefined, and, unmeasured. There are many navigational 'aids' proposed and yet no breakdown of the navigation problem and what those aids are expected to assist. There are very few studies that include more than one condition so the results are unrevealing. The field has implemented many promising navigation aids but has not developed them from a theoretical position or investigated or measured the effects of the aids convincingly.

An exception is extensive comparison of the versions of the hypertext Superbook with a traditional paper-based format described in Landauer (1995). Subjects were required to answer questions on the book's content and the measure used was the number of questions answered per hour of work. The initial version of Superbook was not as successful as the paper-based format. However, development of subsequent versions revealed that a system that encouraged users to adopt better search strategies eventually led to performance superior than with the paper-based text.

There are a few contributions from the field that should be mentioned briefly. The first are the attempts and methods used to structure and aggregate complex spaces. This is discussed further in § 1.5. The second contribution is the measures of hypertext usability and measures of information retrieval which may be relevant to the retrieval of information in a process control situation. These measures will be discussed in § 1.4. Before applying these measures however, it is important to discuss the similarities and differences between controlling a power plant and retrieving hypertext information.

Discussion: Differences between controlling a power plant and retrieving hypertext information. Ignoring the most obvious differences, the most critical difference is that a power plant interface must be constrained by a physical structure, that being the structure and physics of the plant. In comparison, the hypertext task is relatively unconstrained. This is the difference between a correspondence- and a coherence-driven work domain (Vicente, 1990). In the hypertext case, the user's mental model becomes much more important. From the power plant interface, the user must understand the plant. It makes sense for a hypertext user to tailor an interface to match his or her usual search goals. The power plant operator's goals, however, should be consistent with the designed purposes of the plant.

For these reasons, the problem of designing a hypertext interface and a process control interface must be quite different. The process control interface must adhere to displaying the physical behaviour and constraints of the plant. Although the hypertext domain has proposed several aggregating methods, the aggregation of a physical plant is less arbitrary and the abstraction and aggregation space of Rasmussen (1985) is directly relevant and has been investigated more thoroughly. The hypertext domain has provided several examples of navigation mechanisms which may prove to be worthwhile.

However, the lack of theoretical justification and experimental verification of these mechanisms means that they should not be adopted naively.

The power plant tasks are quite different. Hypertext systems are most often used for information retrieval and therefore the retrieval task and measures are worthwhile indicators of the usefulness of the system. With the exception of accessing procedures, the closest analog to the information retrieval task in process control would be the task of fault detection. In the power plant, the information is dynamic and always changing, the hypertext information base is relatively static. The power plant interface must provide for control - the operator can influence the system. In contrast, the hypertext user has little influence over the system, typically an information database.

In terms of using these approaches for measuring navigation in the process control domain, only one direction seems possible. In the case of a fault detection task, information retrieval measures would be worthwhile. There are few, if any, measures though that are directly relevant to navigation and what is available will need more description and development before it would be usable.

Conclusions

It has been seen that adding functional information to interfaces can have many benefits. In adding this information to larger systems, however, there is a danger of adding to problems already encountered in computer interfaces for those large scale systems. Those problems are primarily losses of integration and connection which make it difficult for operators to navigate through those systems. For this reason, the literature on navigation, in both physical and computer environments was reviewed. It was seen that a definition of navigation was the “purposeful control of motion from place to place” (Anderson, 1983).

The concept of *purposeful control of motion* appeared in several places. Gibson, and Shaw and their colleagues emphasized the important role that intention or purpose plays in navigation. Understanding the purpose behind the motion and then viewing this purpose in the context of the environment in which the motion takes place can explain why people go where and why they take certain routes. This is a promising approach because in the case of a power plant interface, the goals and purposes can be outlined quite specifically. This will be seen in the next section.

The second part of the definition states that navigation involves going *from place to place*. More specifically, it might be said that navigation involves going from an origin to a goal. This idea of goal-directedness was emphasized in Shaw's approach. This part of the definition also requires that navigation take place in an environment. Part of understanding navigation, therefore, will require understanding what is important about that environment. Benedikt developed quantifiable ways of describing architectural environments. Gibson discussed developing a description that involved a useful information relation between the operator and the environment. Shaw and his colleagues added to that information field a field of action capabilities. Although these approaches were developed for natural environments, there is nothing limiting them from extending to virtual environments someday.

Some important issues have also arisen out of this look at the literature. Because navigation is *purposeful* it will be critical to understand the purpose of the user of the system. Correspondingly, the experimental task chosen will be critical since this establishes the purpose for the operator and will affect any evaluation of the navigation which is seen resulting from that task. Because navigation involves *control of motion*, an evaluation must give the subjects control over their locomotion through the system. Because navigation occurs *from place to place*, the environment it takes place in must be well understood. In order to understand the power plant system in this study, the next section presents and discusses two different approaches which were taken in modeling the plant environment.

DETERMINING INFORMATION NEEDS

It was seen in the previous section that providing functional information displays can improve operator performance. This section looks at how the information for those functional displays is determined within the context of the ABB conventional power plant. Two different analysis methods were used in combination. Rasmussen's (1985) field studies of decision-making led him to propose the abstraction hierarchy as a tool for determining the information needs of problem-solvers in complex systems. A parallel, but slightly different design technique is the multi-level flow modeling (MFM) proposed by Lind (1990, 1991a, 1991b, 1993). The following sections discuss the abstraction hierarchy and MFM techniques and the use of these techniques in determining the information needs of the operators.

Abstraction Hierarchy

From field studies of decision-making by process plant operators and computer and electronics troubleshooters, Rasmussen (1985) has argued that decision makers move from system goals to the component of interest in a manner that reflects functional reasoning. From these observations he has provided a framework he has called the *abstraction hierarchy*. The abstraction hierarchy is a representation of the properties and constraints of a system which are necessary for that system to operate as designed. Since the hierarchy represents the physical and functional constraints and relations which must hold in order for the system to operate as designed, the abstraction hierarchy can serve as an analytical design tool to determine the information needs of the operator (Rasmussen, 1985; Vicente & Rasmussen, 1992). Rasmussen's abstraction hierarchy has five levels ranging from system purposes, Functional Purpose, to Physical Form, describing the condition, location and appearance of the plant equipment. Rasmussen has also added a dimension of aggregation from system, to components. The aggregation dimension describes the system at different levels of resolution, from very coarse (whole) to very fine (part). In conjunction with the dimension of abstraction, these two dimensions form a two dimensional constraint space.

In more detail, Rasmussen's abstraction categories are:

Functional purpose: System objectives. For a power plant, this would be to produce electrical energy and maintain safety.

Abstract function: Intended "causal structure" (Rasmussen, 1985) or first principles. For a power plant this would consist of mass and energy topologies based on conservation laws.

Generalized function: Processes to achieve the abstract function. An example of a process to transfer energy would be heat transfer.

Physical function: The properties of the components used to drive the process. For example, a component to achieve heat transfer is a heat exchanger.

Physical form: The physical appearance, materials, forms and locations of the components.

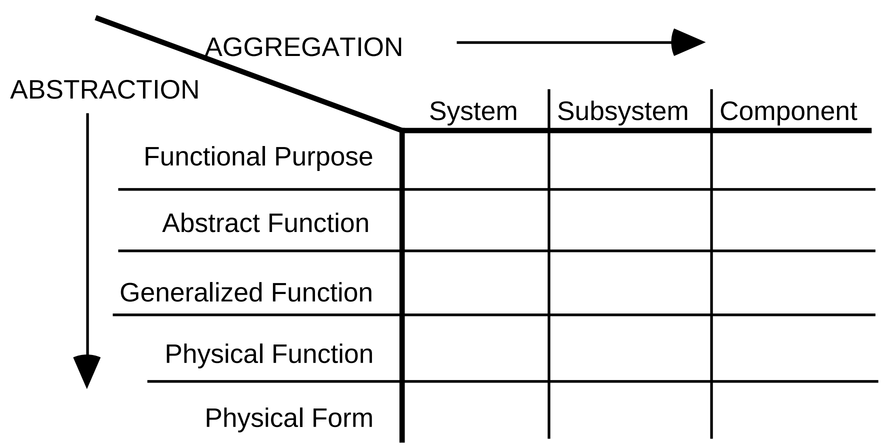


Figure 4. The abstraction hierarchy of Rasmussen (1985).

Abstraction hierarchy models span this two dimensional space (Figure 4). Abstracted information is identified at each level and connected to information at other levels by way of means-ends links. Usually, however, the diagonal or near-diagonal combinations of abstraction and aggregation are most practical. The following figure, Figure 5, shows a small example of an abstraction hierarchy. For a larger example, see Figures 8, 9, 10, 11.

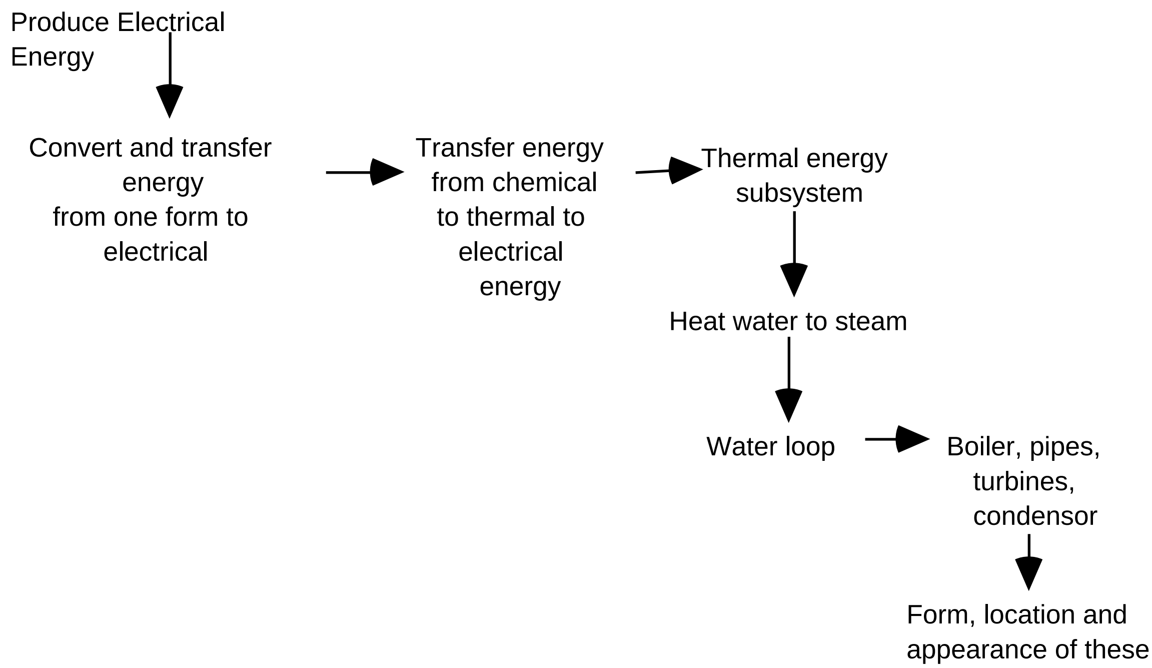


Figure 5. Diagonal elements of an abstraction hierarchy.

Some advances in interface design have developed directly from using the abstraction hierarchy as a design tool (e.g., Vicente & Rasmussen, 1992; Dinadis & Vicente, 1994; Dinadis & Vicente, 1996) . Many new display ideas support certain kinds of functional information even if they were not designed based on a complete abstraction hierarchy. Burns & Vicente (1995, 1996) provide a review of several new display techniques and an evaluation of how they contribute to providing the kind of functional information recommended in an abstraction hierarchy analysis.

Multi-level Flow Modeling

A different technique is the MFM proposed by Lind (1990). Again Lind begins with the idea of modeling the purposes of the system and then proceeding to different levels of system information. Lind proposes two distinct levels of information: goals and flow structures, which implement goals. Lind’s flow structures are built out of “primitive function concepts” (Lind, 1991b) such as source, sink, transport and barrier. These function primitives are one of the most distinctive features of the MFM technique and Lind has developed a symbology for these functional primitives (Figure 6). Lind’s flow structures differentiate between flows of mass and energy and his functional primitives exist in both mass and energy forms. Lind’s levels are also joined by different kinds of links. Figure 7 shows a small MFM model for part of a conventional power plant.

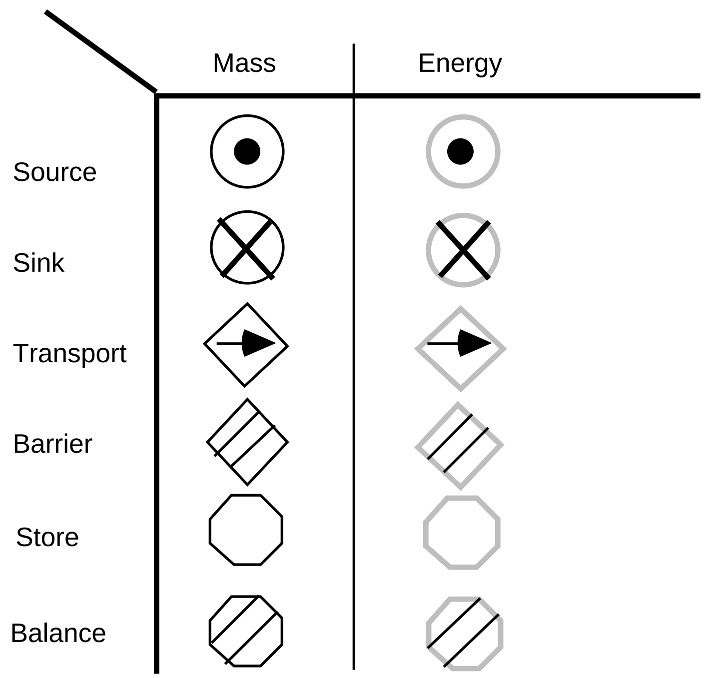


Figure 6. Lind’s functional primitives and symbology.

The symbols for Lind's primitive function concepts are shown in Figure 7. Every model should contain a source and a sink. The difference between obtaining mass or energy from a source and a store is that, for modeling purposes, sources are considered to be limitless supplies. Similarly sinks are modeled as having limitless capacity. So, in the power plant example, the “limitless” source is the coal supply and the sinks with near limitless capacity are the lake, the environment and the electrical grid. Balances are used in those cases where no significant mass or energy is stored and balances may have multiple inputs and outputs. In contrast, stores do retain mass and energy and are restricted to one input and one output. Transports are used for movement or processing of mass and energy, and barriers are used to indicate important functional separations between mass and energy processes.

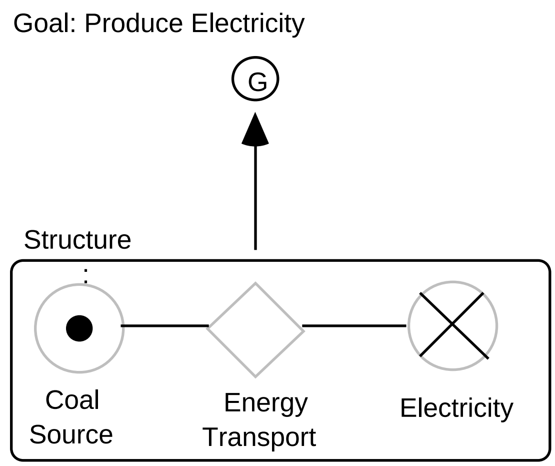


Figure 7. An MFM model showing goal and structure.

Similarities and Differences between Abstraction Hierarchy and MFM

It is worthwhile to compare and contrast the two techniques of abstraction hierarchy and MFM. Both have originated from a control systems perspective and both have been proposed for improving the process of interface design for the design of complex systems (Lind, 1991a; Vicente, 1992 are examples). Both are structures, both are based on the domain of the system, and both emphasize the importance of understanding the system purpose. Rasmussen's structure is a definite hierarchy with a set of distinct levels clearly ordered one above the other. In contrast, Lind's structures are admittedly cyclic "*This circularity in the MFM model illustrates the fact that abstraction levels in an MFM model often combine into cyclic networks of goal and means (i.e. they are not structured* *as trees).*" (Lind & Larsen, 1993, unnumbered pages). The cyclic nature of MFM structures can be demonstrated (Burns, 1996).

Much of this difference can be attributed to differences in the definition of goals that the two techniques use. Rasmussen abstraction hierarchy permits only system purposes as goals whereas Lind's MFM technique permits both system goals and operational goals. Operational goals can be task-oriented and constrained by equipment and physical structure. System purposes, however, are purely intentional goals. When system purposes and operational goals are intermixed the situation arises where operation goals support system purposes. This is because system purposes, being purely intentional means must always be supported by concrete operational ends. This goal supporting goal cycle is what makes MFM create networks rather than hierarchies. However, when the hierarchy ranges from intention at the highest level to physical constraint at the lowest, as in Rasmussen's abstraction hierarchy, it becomes an "affordance structure" (Vicente & Rasmussen, 1990), or rather a structure of physical properties considered in light of a human need. This concept of affordance is drawn from the work of Gibson (1979).

One of the strongest similarities between the abstraction hierarchy and MFM is between Lind's flow structures and Rasmussen's level of abstract function. Both deal with the flow and transfer of mass and energy and are particularly useful in the analysis of energy systems. Much of the strength of MFM lies in representing the abstract function level through mass and energy flow structures at varying levels of resolution.

Modeling the ABB conventional power plant

In modeling the ABB conventional plant, both abstraction hierarchy and MFM models were developed. The goal has been to use the two techniques together to gain the benefits of each of approach. Specifically, the abstraction hierarchy was used first to determine the five levels of information and the important levels of aggregation. Then MFM models were developed to outline the mass and energy functions at the abstract function level in more detail. Generalized process and Physical Function levels were developed from the plant diagrams. The original abstraction hierarchy models were used to identify aggregation levels at which to develop different MFM models. This process led to a detailed understanding of the plant at different levels of functionality and aggregation. To summarize this process:

1. Abstraction hierarchy to define different ordered levels of information.

2. MFM to develop detailed mass and energy flow structures at the abstract function level.

3. Abstraction hierarchy to identify useful levels of aggregation to develop MFM models at.

The following sections describe the abstraction hierarchy and MFM models which were developed.

<u>Abstraction hierarchy models.</u> The abstraction hierarchy model developed is shown in Figures 8, 9, 10, 11. The model was detailed at the five levels of abstraction and for 4 major divisions of aggregation. The four divisions of aggregation used were: a) complete system; b) subsystems c) individual subsystem, water cycle and d) components of the water cycle.

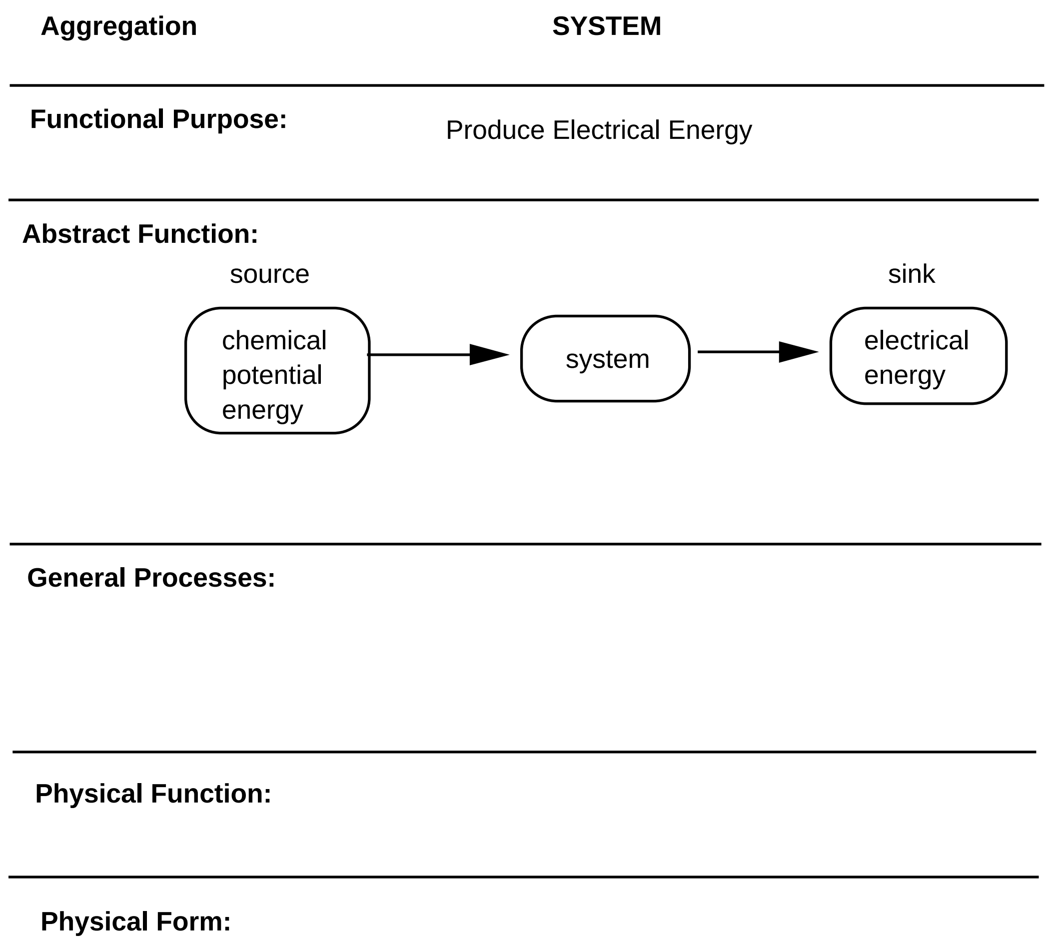


Figure 8. Abstraction hierarchy model at the system level of part-whole decomposition.

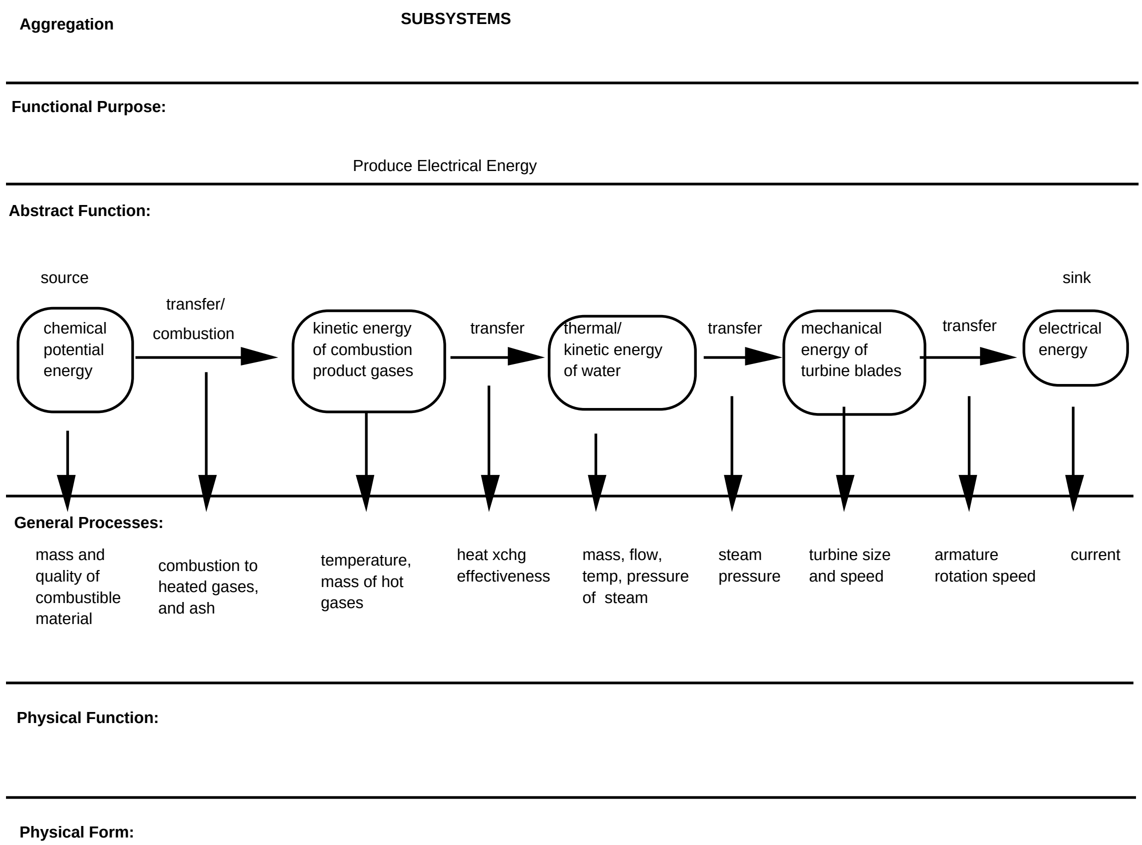


Figure 9. Abstraction hierarchy model at the subsystem level of part-whole decomposition.

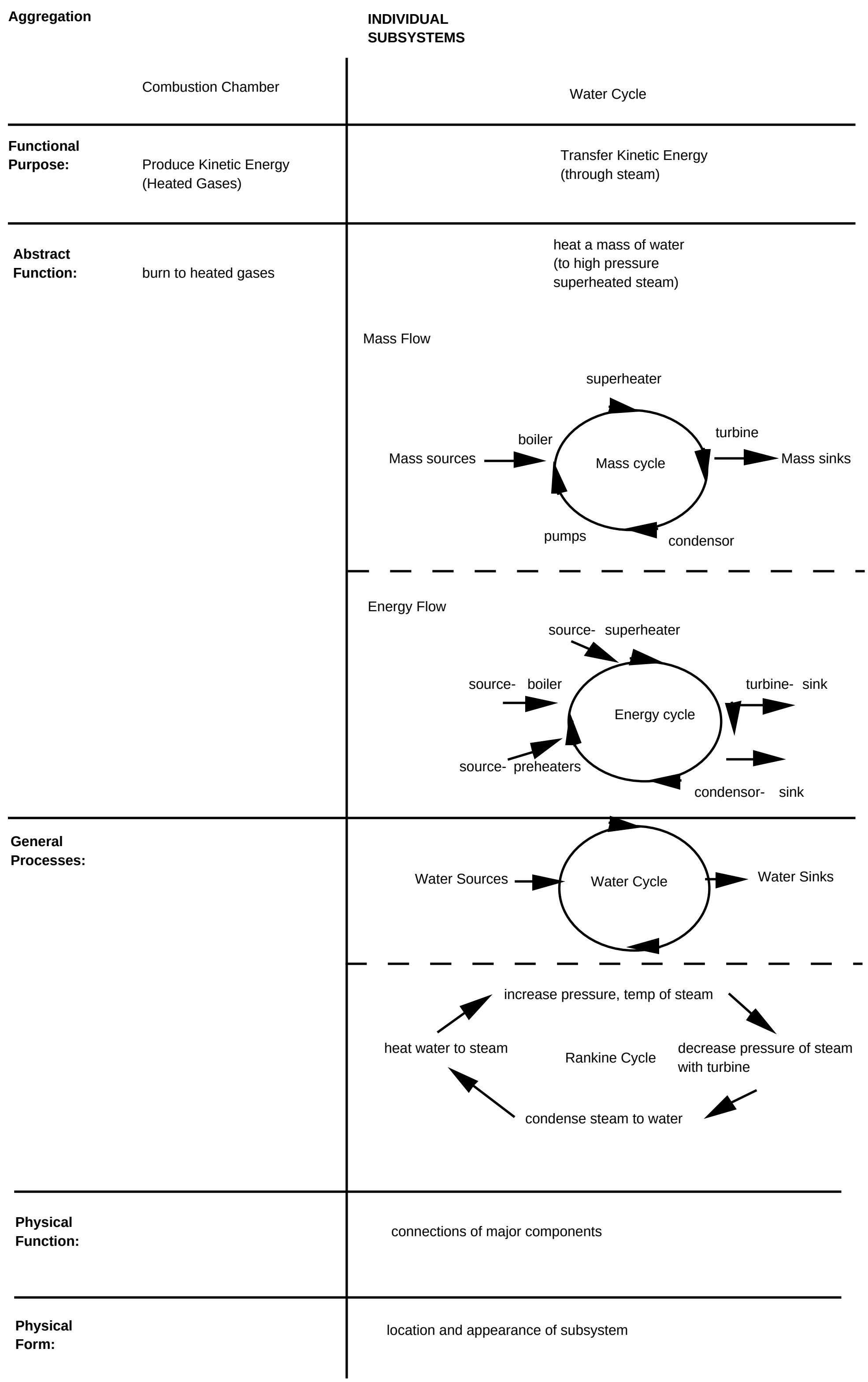
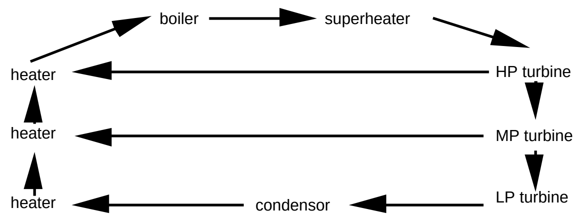


Figure 10. Abstraction hierarchy model of part-whole decomposition showing individual subsystems - the combustion chamber and the water cycle.

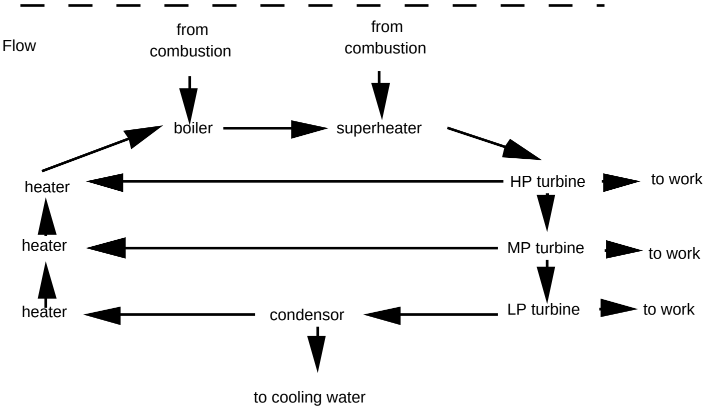
Aggregation	WATER CYCLE - MORE DETAIL	COMPONENTS HEATER
Functional Purpose:	Transfer Kinetic Energy (through steam)	

Abstract Function:

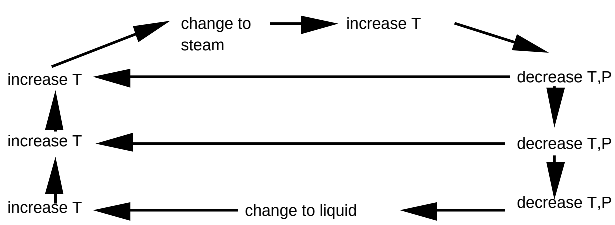
Mass Flow



Energy Flow



General Processes:



Physical Function:	connections of components	setting, capacity
Physical Form:	location and appearance of subsystem	appearance, condition

Figure 11. Abstraction hierarchy model giving more detail on the water cycle. Component level of part-whole model for the heater.

MFM models. The mass and energy flow structures were developed because they provide the most abstract function detail in the MFM models. The flow structures were developed at the same levels of aggregation as the abstraction hierarchy models. All models are at the level of abstract function and are either mass or energy flow models.

Model 1: Energy model at system level aggregation. At this level of aggregation the system is represented as a whole. There is one energy source, that being the coal, and one energy sink, that being the electrical grid. The plant is not decomposed but represented simply as a transport process connecting the source to the sink.

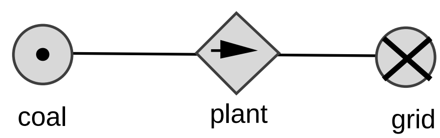


Figure 12. Model 1: Energy model at system level aggregation.

Model 2: Energy model at the subsystem level. At this level, major subsystems can be seen. The major subsystems for this plant consist of the combustion chamber, water system, and generator. These subsystems have been modeled as energy balances as they receive input energy and dispense output energy to one or more sources. One example of a dual output balance is the combustion chamber which outputs energy in the form of heat to the water system and waste energy in terms of heated combustion gases to the environment. The other example is the water system which outputs energy in the form of steam to the turbine shaft and waste energy in the form of heated water to the cooling water system which ultimately ends up in the lake. For the most part these subsystems do not store energy for long periods of time and that is why they are not modeled as energy stores. There are transports between these balances such as the combustion process, heat flow, shaft work, and cabling. More sinks for the system are now visible, those being the lake and the environment.

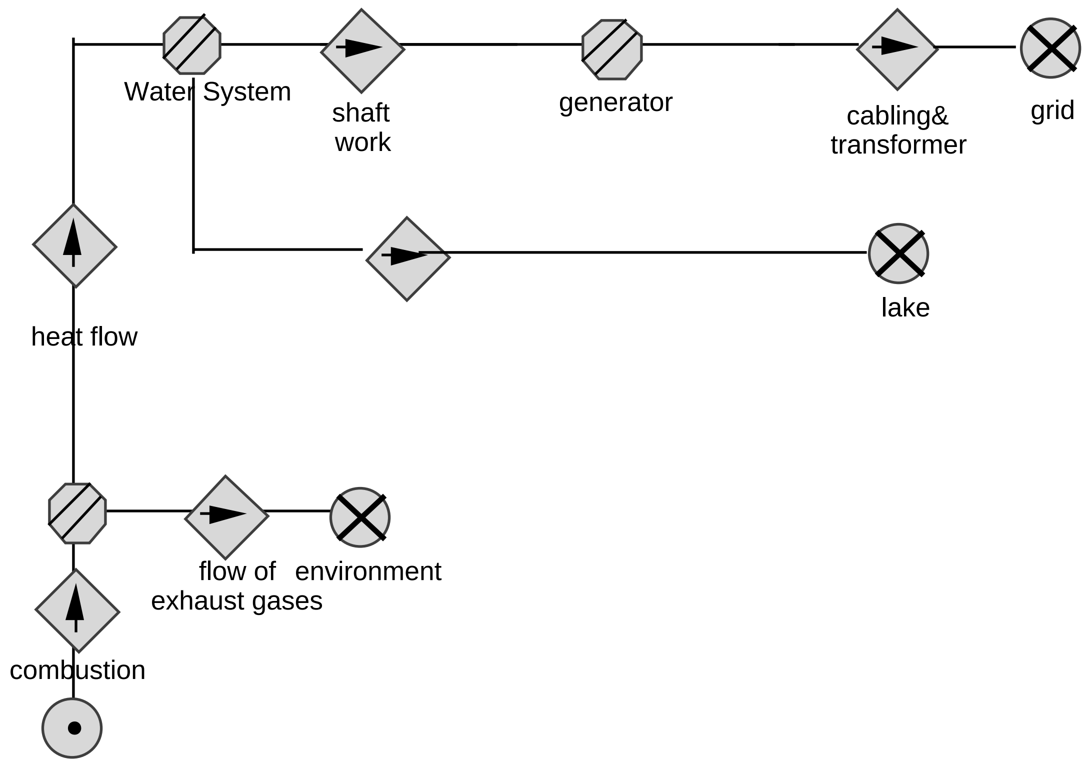


Figure 13. Model 2: Energy model at the subsystem level.

Model 3: Energy model showing individual subsystems, major units (like turbines) are still aggregated. At this level, the major components of the subsystems are detailed. Note that the water system is now decomposed into its major components (boiler, turbines, heaters). These components are still aggregations e.g. the system has three turbines which are still treated as one unit here. In order to model the condensor it was decided to model it as an energy balance connected to an energy sink, that being the lake.

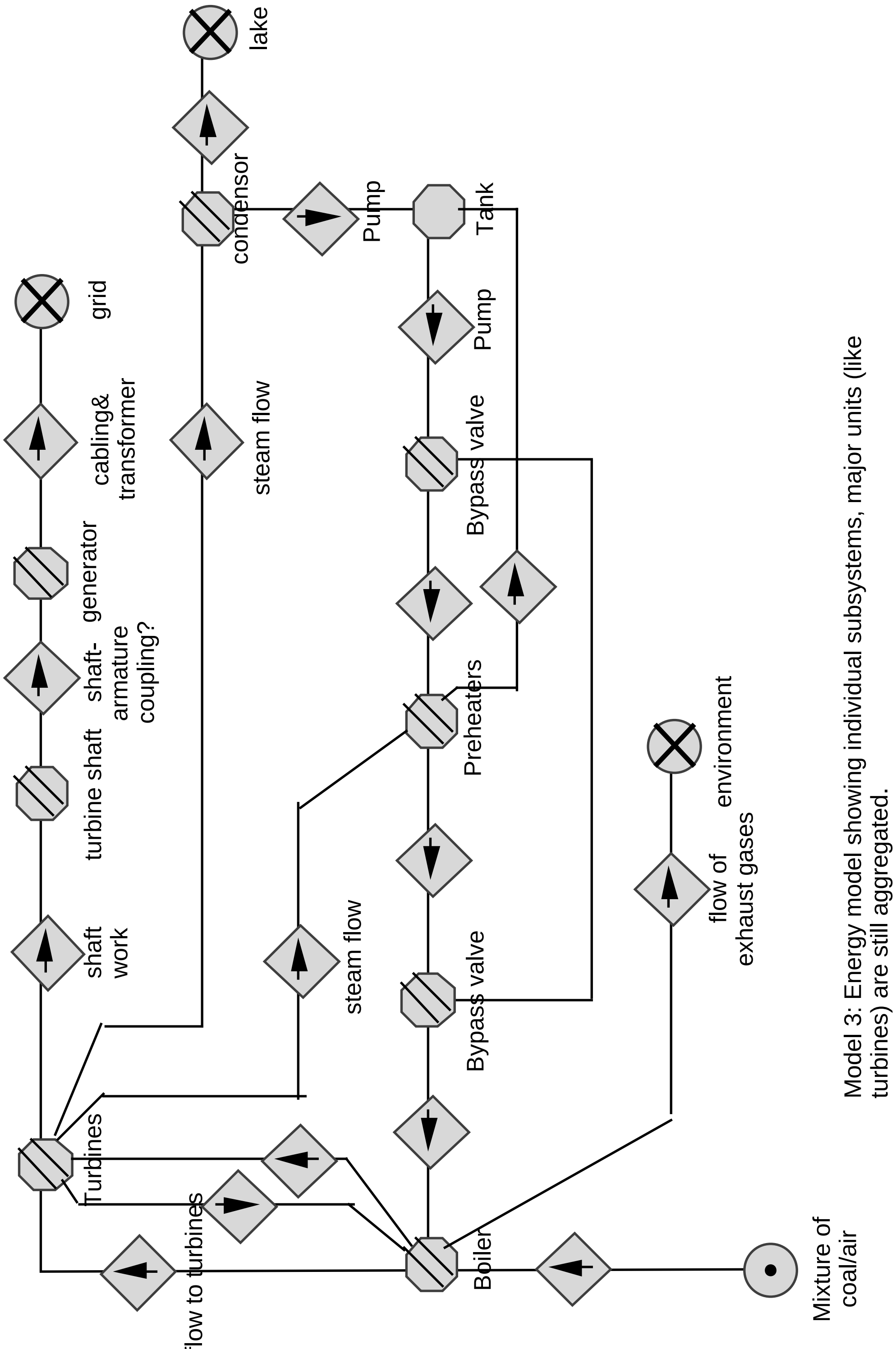


Figure 14. Model 3. Energy model showing individual subsystems, major units (like turbines) are still aggregated.

Model 4: Energy model showing components of the water cycle. The system is outlined here at the component level. The complexity of connections within the boiler are detailed in the grey background box. All three turbines are shown. Similarly bypasses and connections are shown. Occasionally, energy models of power plants have shown the energy flow as progressing from one turbine to the next by connection with the turbine shaft (Lind, Larsen & Hansen, 1993). For this model, however, it was decided to isolate the turbine shaft as an energy-receiving entity. Energy flows from one turbine to the next by way of the transport of heated steam. This model is a more detailed depiction of the structure of the system. Sources and sinks have not changed from Model 2.

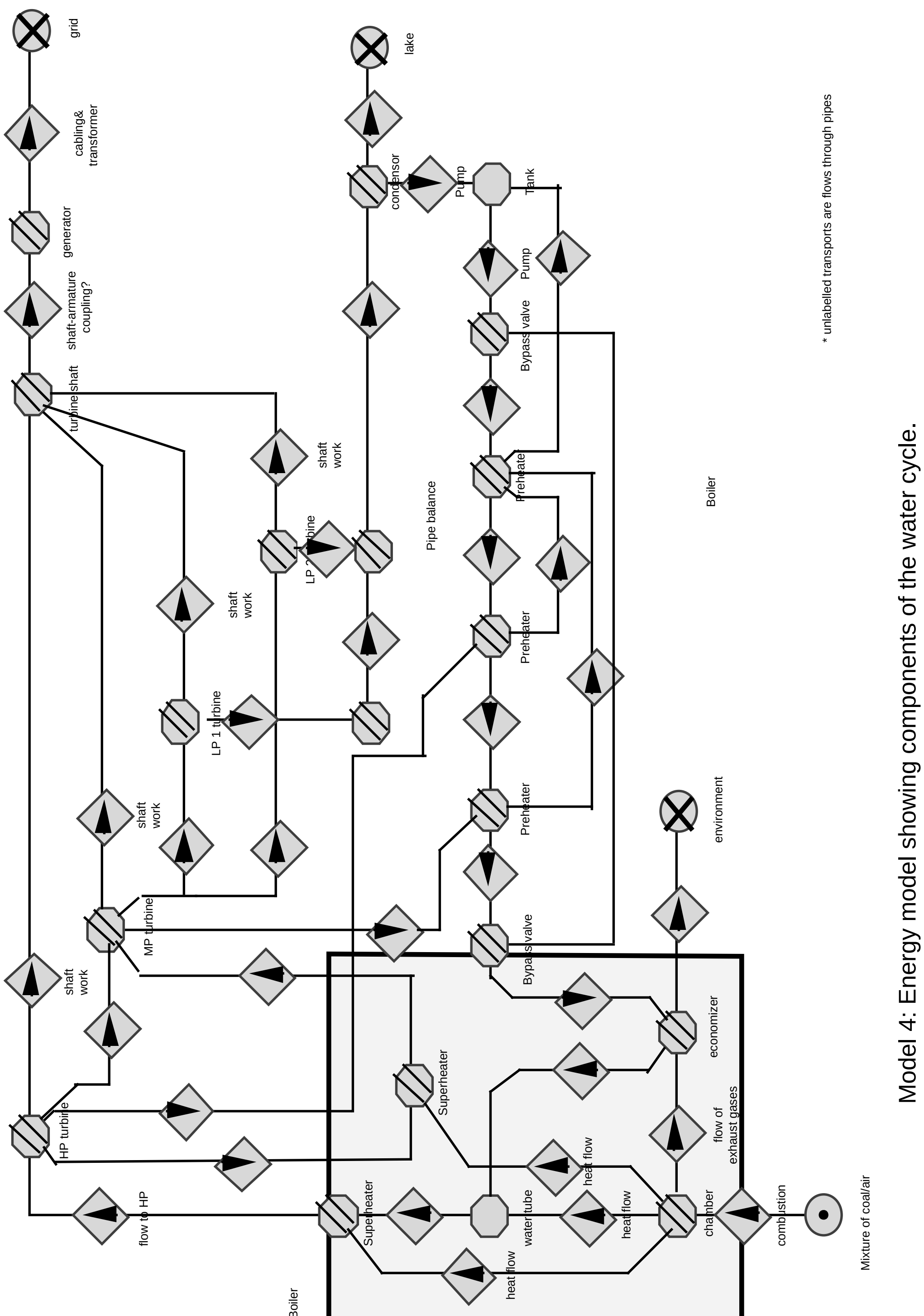


Figure 15. Model 4: Energy model showing components of the water cycle.

Mass model at the system level? A mass model was not developed at the system level because there is no direct transportation of coal mass through the plant. This is in keeping with the purpose of the plant to be an energy conversion system. For this reason, mass models are started at the level of subsystem aggregation.

Model 5: Mass model at the subsystem level. At this level, some of the difficulty in developing a mass model at the system level can be seen. There is a coal transport subsystem which delivers coal to the combustion chamber and removes ash and flue gases. There is a water transport system and a cooling water system. There is also a current transport system, though it could be argued that current is primarily energy and not mass. However, these systems are isolated from each other and therefore this isolation has been modeled by using barriers. Comparison of this model with Model 2 should immediately show how the mass and energy models of a system can be distinctly different.

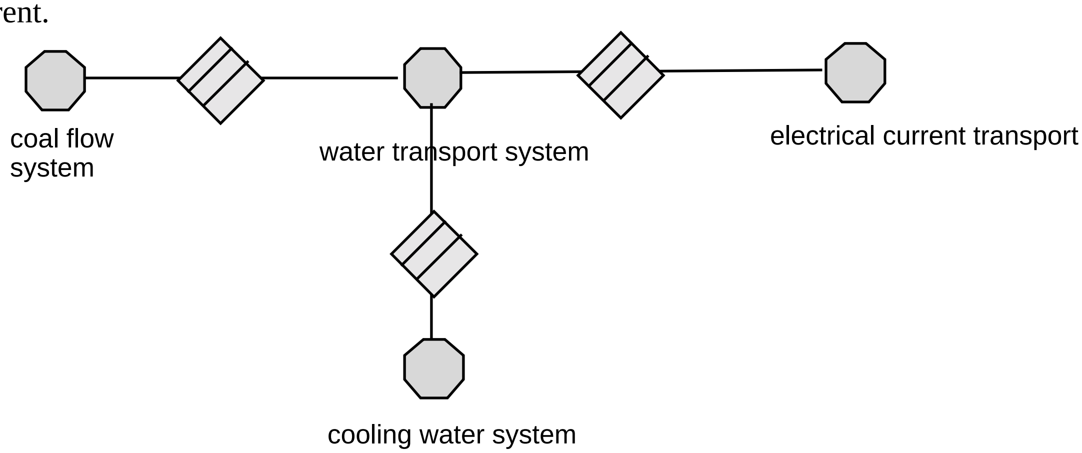


Figure 16. Model 5: Mass model at the subsystem level.

Model 6: Mass model showing individual subsystems, major units (like turbines) are still aggregated. At this level, the major units of the water system are made visible. In comparison with Model 3, some of the functional models of the components have changed. The storage tank, preheats and boilers have been modeled as storage functions since they are capable of retaining some mass of water. In contrast, the turbines and condensors are still modeled as balances.

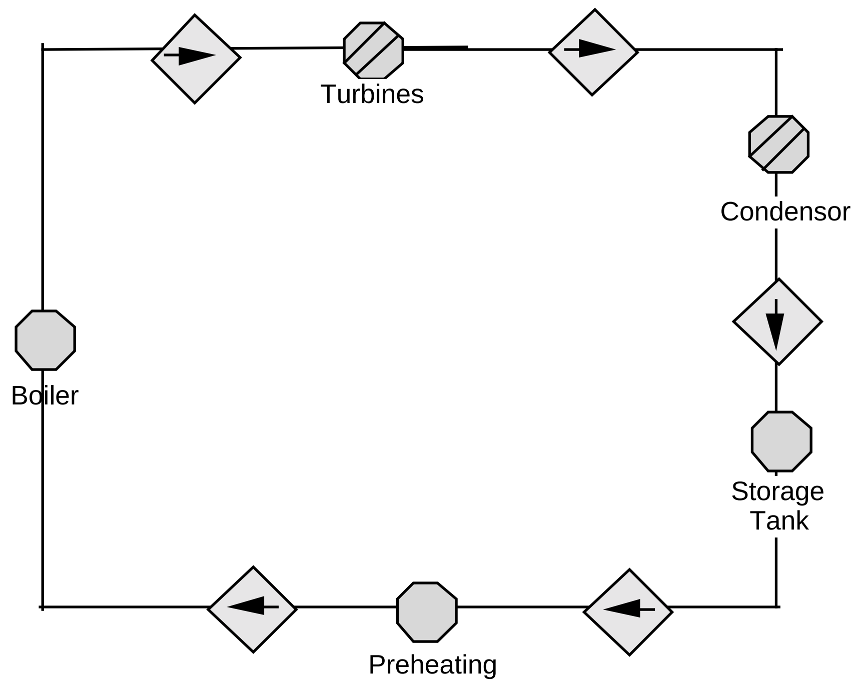


Figure 17. Model 6: Mass model showing individual subsystems, major units (like turbines) are still aggregated.

Model 7: Mass model showing components of the water cycle. The water cycle is detailed here to the same level of aggregation as in Model 4. The cooling water system has been included to show its energy connection (Model 4) but mass isolation (Model 7).

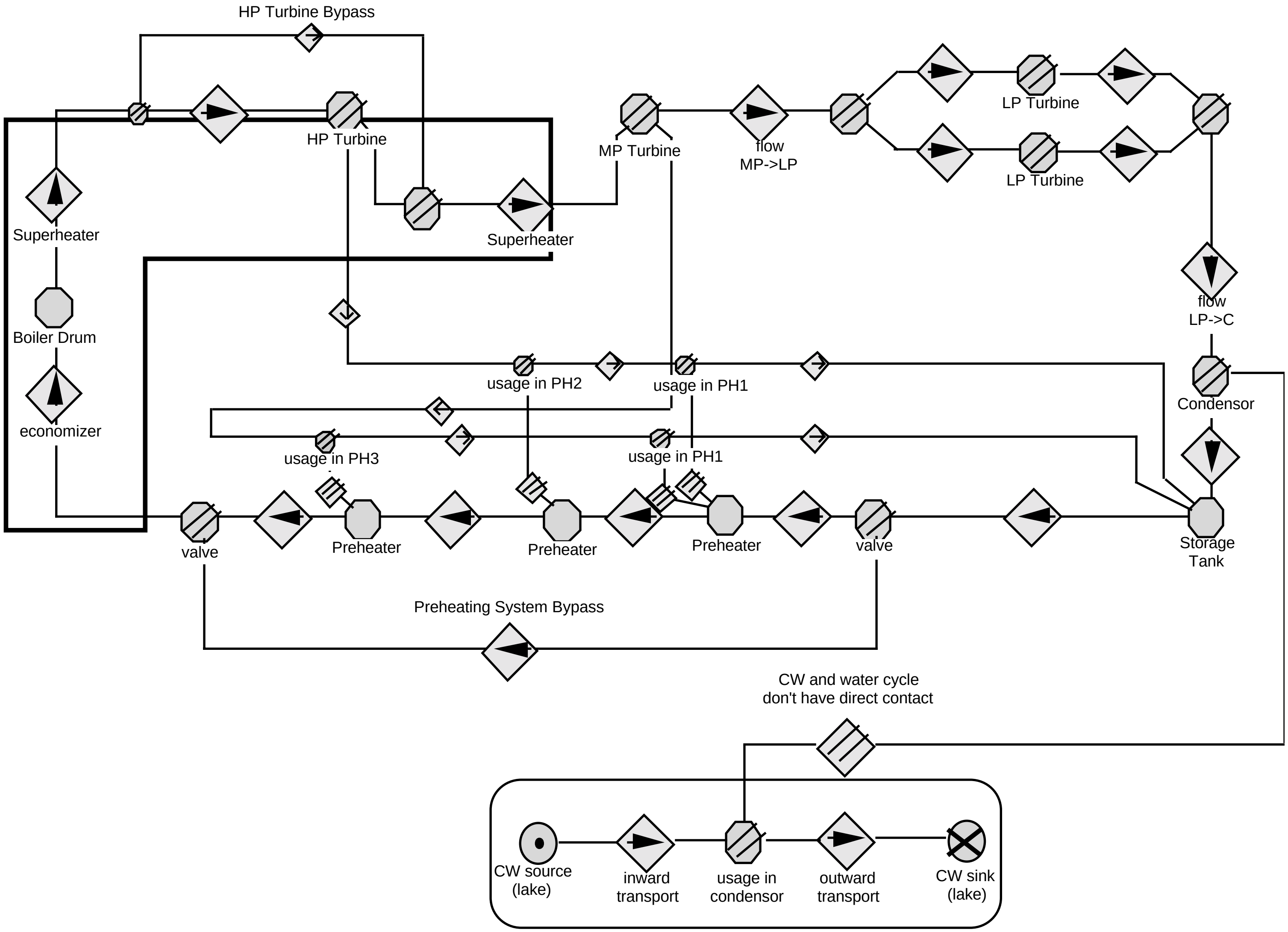


Figure 18. Model 7: Mass model showing components of the water cycle.

Conclusions

Determining what information should be displayed is an important issue. The abstraction hierarchy of Rasmussen and the MFM of Lind are two techniques for systematically determining the functional information of a system. Although different, both are based on a definition of function that relates to plant purposes. Both, therefore, are beneficial analyses for revealing what information will aid the operator in meeting plant purposes.

There are differences, however, in the nature of abstraction hierarchy and multi-level flow models. As a result, they have been used differently in this project, trying to capitalize on the strengths of each technique. This approach has been used before by Goodstein (Vicente, 1992). The abstraction hierarchy has clearly delineated and ordered levels of information, so it was used to outline information at five different levels of abstraction. MFM is not as useful for stratifying information. MFM, however, is a formal grammar and has powerful descriptions of mass and energy structures. Accordingly, it was used to analyse the abstract function level identified from the abstraction hierarchy in greater detail. Aggregation rules for MFM are just beginning to be developed (Fang, 1994a, 1994b), so the aggregations from the abstraction hierarchy were used to develop MFM models at different levels of aggregation. This process is depicted in Figure 19.

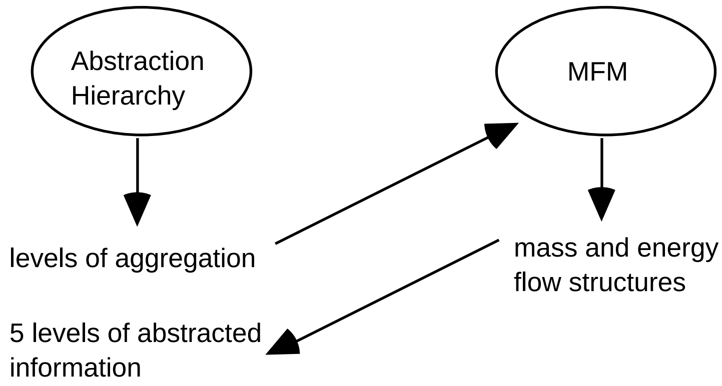


Figure 19. A beneficial way to use both abstraction hierarchy and MFM models in analysing a plant.

In all, there was one abstraction hierarchy model developed at five levels of abstraction and four levels of aggregation. Seven MFM models were developed, four energy models and three mass models, based on the aggregation levels determined by the abstraction hierarchy. It can be seen that an interface providing this functional information will be providing alot of information beyond a traditional physical interface. The issues of integration are more critical with these interfaces because they are designed to support a specific navigation pattern - that being navigation from system purposes to plant components. This navigation requires the operator to understand and make use of the links between the functional levels. It is imperative, therefore, that these links be well-supported within the interface. If not, the danger is that the links will not be navigated and the functional information and its accompanying benefits will be lost. This is the focus of the experiment proposed in the final section. The next section presents some further background needed before describing the proposed experiment.

INVESTIGATIONAL BACKGROUND

This section presents background which was used directly to determine the methods and techniques used in the experiment proposed in the fourth section. First, previous evaluations of multi-level interfaces incorporating functional information are reviewed. Next, design solutions that have been proposed to alleviate navigation problems are presented. In order to evaluate the success of a design solution though, measures of navigation are needed. Possible measures are presented in the final section.

Implementations and Evaluations of Interfaces Incorporating Functional Information

This section discusses other significant implementations and evaluations of functional displays. The particular cases presented are the Generic Nuclear Plant (GNP) implementation and interfaces by Goodstein (1982) and later by Sassen et al. (1994). The evaluation of the Rankine cycle display is discussed. Finally, the results to date of the studies of the DURESS simulation and interfaces at the University of Toronto are presented.

The Generic Nuclear Plant. One of the first uses of the ideas of functional information and MFM occurred in the development of the interface for the Generic Nuclear Plant (GNP) simulation at the Risø National Laboratory in Denmark. The GNP was a simulation of a simplified pressurized water reactor nuclear power plant (Goodstein, 1982, 1985a; Goodstein et al., 1984). Primary, secondary and cooling loops as well as major components were simulated. The display set consisted of equipment displays at five different aggregation levels and some functional information displays. Physical “equipment” displays resembled standard mimic displays. The functional displays were implemented as mass and energy flow diagrams using the MFM symbology. Abstract function was the only functional level implemented (Vicente, 1992). Empirical study of the use of these displays was quite limited and merely exploratory (Goodstein, 1985b; Vicente, 1992).

The Halden Experiment. Vicente (1992) has summarized and described the results of a further study of an MFM-based interface for the GNP conducted by Hollnagel, Hunt, Praetorius, and Yoshimura in 1984. Subjects were given 6 hours of training and the task consisted of identifying three transients. Subjects reported difficulty in mapping the

MFM concepts to the plant simulation. The investigation was also plagued with some implementation difficulties. The conclusion of the experimenters was that the MFM grammar may be most useful at the level of abstract function but less useful at lower levels of abstraction.

Praetorius and Duncan. Praetorius and Duncan continued this line of investigation (Vicente, 1992). They used a larger plant simulation capable of producing more fault scenarios. The interface consisted entirely of MFM symbols in screens at different levels of decomposition. Subjects were given 2 hours of training on 8 fault scenarios. The task was a fault detection task and the subjects were very successful at diagnosing the faults.

Further evaluation of the GNP by Sassen et al. Sassen et. al (1994) conducted a more complete investigation of an interface on the GNP simulation (Goodstein et al., 1984). Her simulation of the GNP produced 74 simulated variables. She had two interface conditions - one with a conventional single sensor- single indicator interface and the other condition with an interface developed using the MFM procedure of Lind (Lind, 1990, 1991a, 1991b, 1993, 1994; Lind & Larsen, 1993, 1994; Lind, Larsen, & Hansen, 1993). Operators were provided with trend diagrams of all 74 variables, three different levels of detail, and an alarm window. The MFM interface also included windows with the multi-level flow model and a diagram of flow structures used for selecting the multi-level flow model.

Sassen et al.'s study consisted of two groups of 6 upper year Mechanical Engineering undergraduates in each interface condition. The experiment consisted of detection and diagnosis of fault scenarios. Before beginning the experiment, all subjects received 12 hours of training. Although Sassen et al were able to demonstrate differences in the search strategies of subjects in the two interface groups, they were unable to show any statistically significant improvement in performance with the MFM interface.

Rankine Cycle evaluation. Vicente et al. (1996) evaluated the Rankine cycle display against two different display interfaces, an analog single-sensor single indicator

(SSSI) display and an SSSI display with a P-T graph. As well, there was a three-level experience factor of novices, experts, and operators. Novices were third and fourth year mechanical engineering undergraduates. The evaluation task was detection and diagnosis of scenarios which were generated from a full-scope NPP training simulator. From the simulator, 35 variables were extracted.

It was shown in Burns & Vicente (1995) that the Rankine cycle display of Beltracchi provides Generalized Function information. Furthermore, the Rankine cycle display is also an example of an ecological interface (Vicente & Rasmussen, 1992) in that the display of system performance against the background of the temperature, pressure, entropy and state relations of water makes the generalized function information obtainable perceptually. Vicente et al (1996) showed that in comparison with an analog single-sensor single indicator (SSSI) display and an SSSI display with a P-T graph that the Rankine cycle display contributes significantly to better detection and diagnosis performance (Vicente et al, 1996). Since pressure and temperature information was available in each situation, all three displays contained functional information. The improved performance with the Rankine cycle display, however, demonstrates the benefits which can be gained when functional information is displayed in a form that makes the critical constraints and relations of the information directly visible.

The DURESS II simulation. The DURESS II simulation is a simulation of a feedwater subsystem. It has two redundant feeds cross-connected to two heated reservoirs to add redundancy and therefore complexity. The simulation has been outfitted with a physical interface and an interface containing both physical and function information for the purpose of studying the benefits of adding functional information. The functional information in the interface resulted directly from an abstraction hierarchy model of the feedwater system (Vicente & Rasmussen, 1990; Bisantz & Vicente, 1994).

Several years of study have shown that the functional interface generally improves operator performance during fault situations (Vicente, 1992; Vicente et al., 1995) and improves operator strategies (Pawlak & Vicente, 1996). Furthermore, it has been repeatedly shown that adding the functional information has had no cost to experienced subjects (Christoffersen et al., 1994; Pawlak & Vicente, 1996; Howie et al., 1996). The benefits of the functional interface have been evaluated in a long term study (Christoffersen et al, 1994; Christoffersen et al, 1996), with various training approaches (Hunter et al., 1995; Howie et al., 1996), and for examination of interaction with individual differences (Howie, 1995; Howie et al, 1996). Providing functional information has been proven to be a robust method of supporting effective operator behaviour in DURESS II.

Designing for Better Navigation in Functional Interfaces

It was seen in the first section that there are many problems associated with developing computerized displays for large scale systems. Primarily, these systems are prone to losses of integration that make it difficult for operators to navigate through the systems. In particular, functional displays, with their multiple levels of information would seem to be especially vulnerable to these sorts of problems.

Designing to improve navigation has not always resulted in immediate success (e.g., de Jong et al, 1993). However, in the area of designing computer displays to improve navigation, two specific approaches have appeared. The first is from efforts to structure hypertext by aggregating information. The second approach is called visual momentum (Woods, 1984).

Structuring and Aggregating Information. As hypertext applications have become more complex people have proposed ways of structuring and aggregating the information space to make it simpler to follow. There are methods of clustering using graph theory (e.g., Botofago & Schneiderman, 1991). There is clustering based on proximity and clustering based on simple semantic rules (e.g., x is a member of group y). There is clustering based solely on the link structure. Interfaces have been implemented demonstrating ‘fish-eye’ views (Furnas, 1986; Noik, 1993), and ‘rubber sheet’ approaches (Kaltenbach, Robillard, & Frasson, 1991). Structure and link maps, and menu-based tables of contents are seen frequently.

Visual Momentum. Drawn from the film industry's need to provide continuity of a story-line between disjoint scenes, Woods describes high visual momentum as "an impetus or continuity across successive views which supports the rapid comprehension of data following the transition to a new display" (Woods, 1984, p. 231). In contrast, he defines low visual momentum as "the equivalent of serial data presentation" (Woods, 1984, p. 231). The goal of this approach is to provide links and continuity visually between disjointly presented information. Some of the techniques to increase visual momentum that he has suggested are:

1. using a fixed format or fixed spatial location
2. using a long shot or overview display to provide system status and orientation
3. providing landmarks across displays for orientation
4. overlapping displays
5. smoothing transitions between displays
6. using techniques such as side views or center surround views which concentrate detailed information in the area of interest and less detailed information in the surrounding areas.

Similar techniques have been discussed in other areas. For example, the technique of "center surround" is very similar to the fish-eye views discussed by Furnas (1986) and Noik (1993). The provision of landmarks and overviews relates to the use of landmark and survey knowledge mentioned in Wickens (1992). Woods' concept of visual momentum, however, provides an explanation of why these techniques may be successful.

These techniques promise greater success than the band-aid approach of adding navigation tools for two reasons. First, they are based fundamentally on a understanding of what is lost in transitions from one view to another. In sharp transitions from one view to another, the relationships and links between the views are lost. Similarly, a narrow focus on individual views loses the greater context of those views, which again places those in relation to each other. The second reason for favouring this approach is that it is feasible. There is no reason why, with today's graphical computing, many of these ideas cannot be implemented. As functional information is added to larger scale systems and loss of integration becomes a danger, techniques for providing visual momentum offer some promise for improving the displays.

Measuring Navigation

After implementing new interface design ideas, it will be critical to evaluate the new ideas to determine whether or not they are truly improving navigation through the interface. From the literature review it was seen that there are many different approaches to understanding navigation. From these approaches, different ways of measuring navigation have resulted. These measures are discussed in terms of performance measures, field measures, and usability measures.

Performance measures. One simple way of measuring navigation in a complex system is just to measure the performance of users operating the system. If their tasks are completed accurately and in a timely fashion, the system is supporting them adequately. Time of solution and accuracy of solution are the primary measures here.

Field Measures. The field descriptions of the environment can lead to novel new measures. From Gibson and Crooks' (1938) analysis of driving fields several measures resulted. Benedikt was able to draw several different measures from his isovist description.

Gibson and Crooks' (1938) defined a field of safe travel which was a relational field between the observer's intention (safe travel) and the constraints in the environment (e.g.. other cars). Based on this field they proposed measures such as the m*inimum stopping zone*, *field boundaries* and *clearance lines*, and a *field zone ratio* equal to the depth of the field of safe travel/depth of the minimum stopping zone. This demonstrates how discovering the correct field description of the environment can lead to novel new measures.

Benedikt (1979) developed many measures based on isovists. An environment can be described in terms of the minimum set of isovists required to see the entire environment. He termed this the *sufficient set* for the environment. The number of isovists in the smallest sufficient sets is the *sufficiency number* for the environment. A *sufficient path* is the path which connects all the vantage points of the sufficient set. The *minimal sufficient path* is the shortest sufficient path.

Taking advantage of the fact that light travels in straight lines, each isovist at a vantage point x has several measures which can be taken as a function of theta, the angle around the vantage point x. One can measure the isovist "length", $L_x(\theta)$, which is similar to considering a point light source at x and then measuring the ray length about that point light source. Benedikt termed this *radial length function* of x. With this function, the variance of the radials, or second moment of the mean, could be calculated, $M_{2,x} = M_x(l_{x,\theta})$. Similarly the third moment, or skewness, could be calculated. There are also scalar measures based on isovists. The area $A_x = A(V_x)$ describes how much space can be seen from x as well as how much space x can be seen from. The perimeter of the isovist, $P_x = |S_x|$ describes how much surface, S, can be seen from x. The occlusivity of the isovist, $Q_x = |R_x|$, describes the depth to which environmental surfaces cover each other when seen from x. Rx is the set of occluding surfaces visible from x. Each of these measures is only for a single vantage point x. By defining these measures across the entire environment, measures of the isovist field can be constructed. Benedikt suggests that these measures may have relevance for explaining human behaviour.

Usability Measures. Most hypertext usability studies deal with the problem of information retrieval. Most tasks therefore measure proportion of hits vs. false alarms, retrieval speed, and proportion of the available relevant material retrieved. Egan et al.(1991) provide a good example of the use of these measures. Other studies have looked at more qualitative measures obtainable by interviews with the users or questionnaires (e.g., Are they using the system? Do they like it?). There have been some studies which asked the subjects to recall the structure of the space afterwards and draw maps of the space as mentioned in Chignell (1992). Some studies have observed users interacting with the system and whether or not they needed to make notes or use memory aids while using the system. Wright (1991) has a good discussion of these studies.

The following list summarizes these measures:

- proportion of hits vs. false alarms
- retrieval speed
- proportion of the available relevant material retrieved
- questions answered per hour of work
- interviews with the users or questionnaires
- can users recall the structure of the space afterwards and draw maps of the space?
- do users make notes or use memory aids

An important part of improving navigation through large scale systems will be the evaluation of new interface ideas. From the different approaches to navigation in both physical and computer environments, however, several ways of measuring navigation have been extracted. These ways of measuring navigation will be useful for evaluating the effect of a new interface on navigation.

Conclusions

There have been several studies of functional interfaces in different process control environments. None of these studies has looked specifically at integrating and smoothing the transitions between functional levels when the functional interface is for a large system. Woods' (1984) visual momentum techniques off promise for supporting functional information by providing visual momentum along functional links. To evaluate these ideas, however, measures of navigation must be developed. Some traditional and novel measures of navigation were discussed in the final section. The next part of this report presents a proposal for an empirical investigation looking at the problems with parsing functional information and the ability to create visual momentum between functional displays using one of Woods' techniques.

PROPOSAL

There is evidence that providing functional information to operators can improve operator performance. There are, however, many problems associated with providing computerized displays for large scale systems. The desire to provide functional information as well as physical information would seem to add to these problems. The use of visual momentum techniques, however, offers promise to improve performance in interfaces for large scale systems.

To accomplish this, it is proposed that physical and functional information displays be developed for a complete power plant, that being the ABB conventional plant to the extent that it has been simulated. Four levels of displays will be developed at the levels of Physical Function, General Function, Abstract Function and Functional Purpose as defined by Rasmussen (1985). Displays of Physical Form will not be developed since these displays require physical information on component appearances and locations, information which is not available with a simulated plant. An initial investigation of different alternative display ideas at each of these levels has already been conducted (Burns & Vicente, 1995).

One of the most promising display ideas from Burns and Vicente (1995) employed the visual momentum technique “display overlap” to provide integration between different levels of functional information. It is proposed therefore to investigate the effects of providing increasing levels of simultaneously visible functional information and the potentially modifying effects of using display overlap to improve visual momentum.

Hypothesis

As the number of simultaneously visible functional levels increase, subjects' performance will improve until a trade-off point is reached at which point performance will decrease as a result of visual clutter. Integration of functional levels through display overlap will improve performance by providing greater visual momentum but will also demonstrate a trade-off point beyond which performance will be poorer.

Experimental Design

As shown in Table 1, it is proposed that the experiment investigate 3 levels of simultaneous functional information display and two levels of display overlap. At the first level of information display, each functional level would be displayed on a separate screen. This is a serial presentation. Only one level of functional information is shown at a time. Figure 20 shows this case. There is no display overlap for this display since an overlapped display would violate the serial display of the information. At the second level of information display, two consecutive levels of functional information would be presented simultaneously (e.g.. Physical Function and Generalized Function, Generalized Function and Abstract Function, Abstract Function and Functional Purpose). Figures 21 and 22 show the parallel display of Physical Function and Generalized Function displays. In the low display overlap case, Figure 21, the displays would be presented simultaneously but isolated in separate windows. In the high display overlap case, Figure 22, the displays would be presented overlapped. The overlapped case should create greater visual momentum to reinforce the connection between the levels of functional information. A similar construction would be followed for three simultaneous levels of presentation.

Levels \ Overlap	No	Overlapped
Serial [1] [2] [3] [4]	I.	Not possible
Low Parallel [12] [23] [34]	II.	III.
High Parallel [123] [234]	IV.	V.

Table 1. Experimental Design.

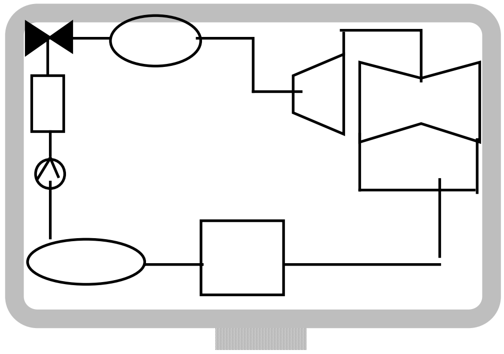


Figure 20. Serial Display, no overlap. Case I.

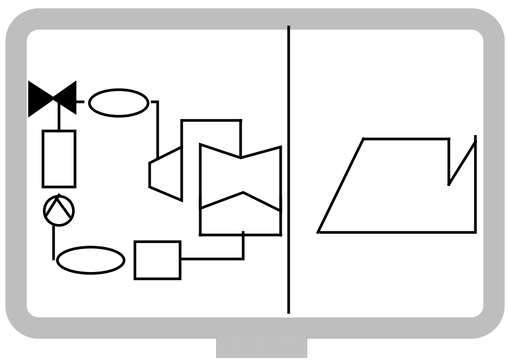


Figure 21. Parallel Display, no overlap. Case II.

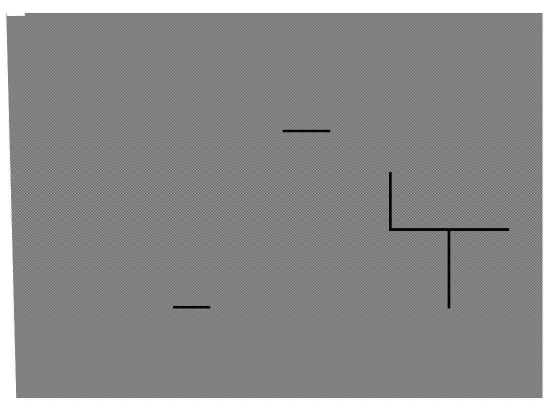


Figure 22. Parallel Display, Overlap. Case III.

In each case the same system is being used and the same functional information is available. The same displays will be used at each level so graphical forms will be held constant. The difference between the conditions is the difference in the amount of information displayed simultaneously and whether or not the visual momentum technique of display overlap is used. It is incorrect to say that the information in each condition is the same since the visual momentum technique provides information on the connections and links between the levels of functional information.

It is proposed that the subjects be given zooming and panning controls but that these actions be recorded as part of the experiment. The experiment designed above also provides a systematic manipulation of the "keyhole" mentioned by Woods and zooming and panning actions may effect this keyhole.

Because the displays are similar in each case, it is expected that subjects would transfer information gained from one condition to the next if this were a within subjects design. Therefore, to avoid transfer effects, it is proposed that this be a between subjects design with two between subjects factors, Display Overlap, and Parallel Display Level.

Predictions.

Prediction #1: Parallel display of levels will result in better performance than serial display. II,III,IV,V>I. This predicted result is shown in Figure 23.

Prediction #1b. There is a trade-off point. The intermediate level of display will result in the best performance. II>I, IV>I, II>IV, III>V.

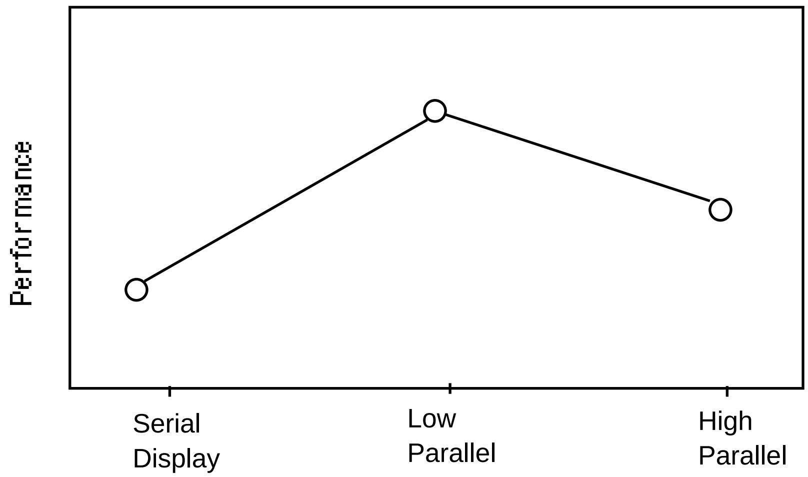


Figure 23. Prediction #1.

Prediction #2: High Display Overlap will always result in better performance than low Display Overlap. III>II and V>IV. This result has been shown in Figure 24.

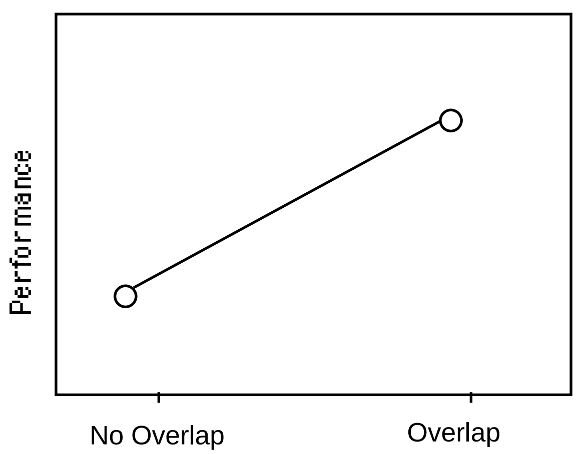


Figure 24. Prediction #2.

Prediction #3: There is no interaction predicted between the level of Parallel Display and Display Overlap. This is depicted in Figure 25.

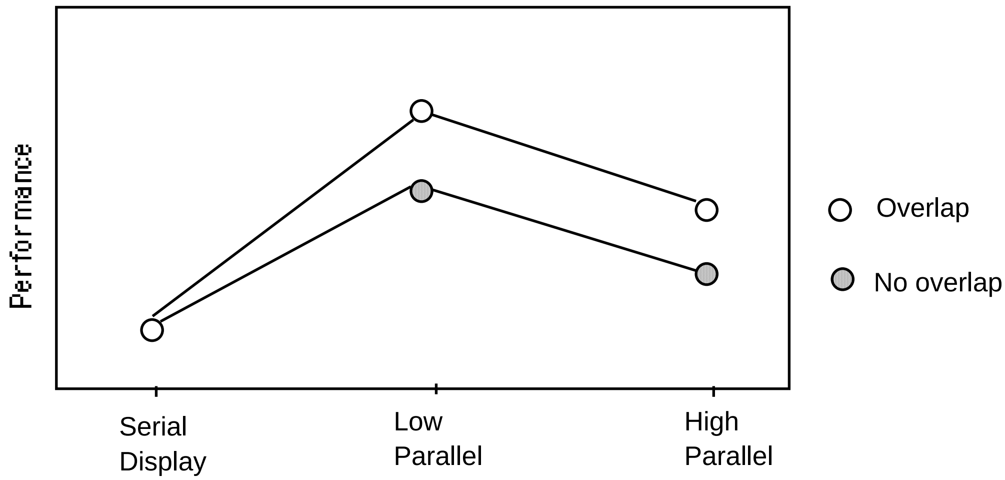


Figure 25. Predicted results

Inferences and Discussion of Alternative Results

Prediction #1 is true. Inference: Parallel display of information provides for better performance than serial display of information. There is however a trade-off point at which there is too much information presented. Parallel display of different functional levels of information provides some benefits in traversing functional links through the retention of spatial configuration across the display windows.

Alternative inference: The gains are solely due to savings in screen-flipping. The performance gain must be greater than the savings from generating the new display.

Prediction #1 is false.

1a. Increased Parallel display brings degradation of performance, shown in Figure 26. Inferences: The additional information is overloading the operator.

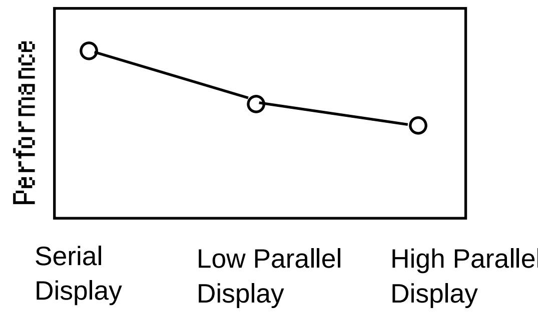


Figure 26. Prediction #1 is false.

1b. There is no difference between the conditions. This possible result has been shown in Figure 27. Inferences: The subjects may be performing the task using only 1 level of information. Another alternative is the dependent variables are not sensitive to the differences in performances and the experiment must be redesigned.

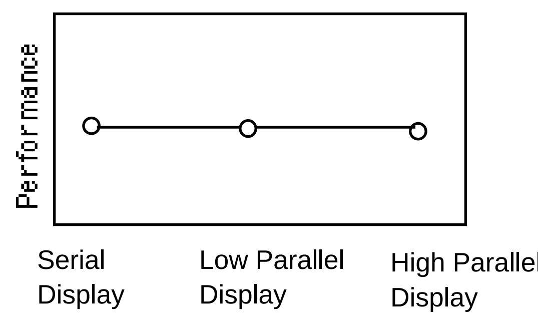


Figure 27. Prediction #1 is false.

1c. Increasing the parallel display improves performance. There is no trade-off point. This possible result has been shown in Figure 28. Inference: The parallel information is providing better than anticipated improvements in operator performance by providing access to more levels of functional information simultaneously. There may be no trade-off point or the trade-off point may lie beyond the conditions which were tested in the experiment.

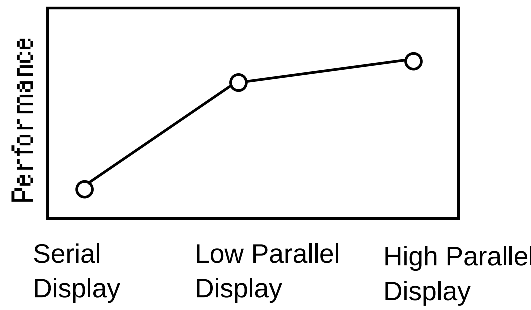


Figure 28. Prediction #1b is false but Prediction #1 is found true.

2. Prediction #2 is true. Inference: The visual momentum technique of display overlap improves the traversing of links between different levels of functional information.

Alternative inference: There is no alternative inference.

Prediction #2 is false. The technique of display overlap provides no significant performance improvement or a performance decrement. These two cases are depicted in Figure 29, the dotted line shows the case of a performance decrement with increasing visual momentum. Inference: Display overlap is not effective at creating visual momentum.

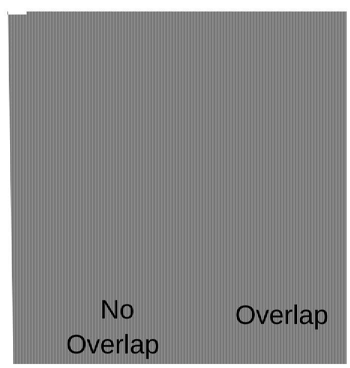


Figure 29. Prediction #2 is false.

Prediction #3 is true. Inference: Display Overlap consistently improves the integration of the display and creates visual momentum.

Prediction #3 is false. There is an interaction between Display Overlap and the amount of information displayed.

3a. The Display Overlap technique is more effective with the highly parallel display. Inference: Display Overlap is more powerful at creating visual momentum than anticipated. This case is shown in Figure 30.

3b. Display Overlap interacts negatively with the increased parallel information display. Inference: As the amount of information displayed increases Display Overlapt is becoming less effective at providing integration across levels of information. This case is shown in Figure 31.

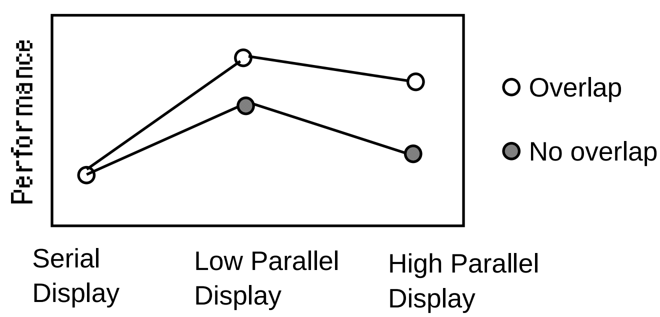


Figure 30. Prediction #3 is false. There is a positive interaction.

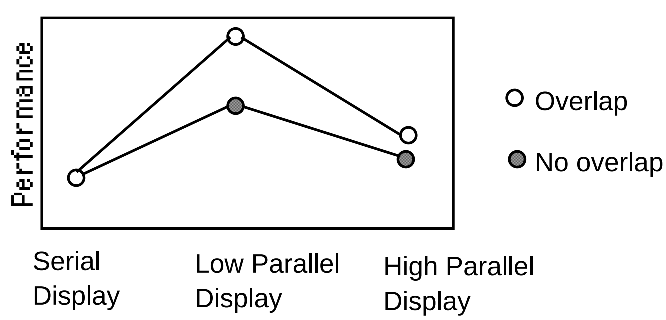


Figure 31. Prediction #3 is false. There is a negative interaction.

Experimental Method

The method to be followed is discussed in terms of pilot testing, subjects, tasks, apparatus, data collection, performance measures, and the representativeness of this study.

Pilot Test. It is proposed that conditions I, II and III be run with a small number of subjects in order to gauge the magnitude of the effects. This information will be used to reevaluate the number of subjects needed, the training procedure, and whether conditions IV and V will prove interesting.

Subjects. The subjects should be mechanical engineering graduate or third or fourth year undergraduate students with at least one course in thermodynamics so that they are familiar with the rankine cycle and t-s diagram. As a first estimate, there should be 6 subjects per cell for a total of 30 subjects.

Tasks.

1. Cognitive Style Test - It is proposed that the subjects complete a cognitive style test on Serialism/Holism as recommended by Howie, Janzen, and Vicente (1996). Howie (1996) has shown that Serialism/Holism is a significant individual difference which correlates with performance on functional displays. The Serialism/Holism test distinguishes between individuals who focus on task details and individuals who are more likely to search for relationships between information and a broader view of the task (Howie, 1995). It is reasonable to assume that individuals with a holist approach will be more successful at navigating the links between functional information. For this reason, it is recommended that the subjects be tested on this cognitive dimension and the subject groups be balanced in terms of cognitive style. The cognitive style test takes 2 hours to administer.

2. Demographics Questionnaire - The subjects will be given a basic demographics questionnaire to determine their age, level of education, number of thermodynamics courses, and the extent any previous experience working with process control systems.

3. Training - Training will concentrate on familiarizing subjects with the plant. At the first session subjects will be asked to read and sign an informed consent form, complete a demographics questionnaire and complete the cognitive style test. Subjects will receive a one hour verbal explanation on the basic design of the plant and the displays available. Although the abstraction hierarchy will not be presented, the displays and the meaning of the displays will be explained. In the second session, the subjects will then be allowed to explore the interface, generate pre-determined faults in the system and observe how the interface behaves during those faults. The subjects will also be allowed to view the interface during normal situations with small transients. In some scenarios, automatic system actions will take place to compensate for the fault. It is proposed that the subjects be given an interface with all four levels of functional information presented simultaneously to encourage the subjects to view and explore all the levels of information. Following this session, the subjects will be given a test on basic applied thermodynamics placed in the context of this particular plant and its interface. Subjects who receive a score of 80% or better on the training test will be allowed to proceed to the data collection phase. This is the same level of pre-test performance used by Sassen et al. (1994). Subjects who do not will receive one additional hour of training and a re-test and will be withdrawn from the experiment if the second test is not successful.

4. Steady State Tasks - The purpose of these tasks is to study how well the subjects use connections between the functional levels of the interface. The tasks will be of two types: 1. Movements Downward in Reasoning: "How" Task: Given a value or relation at the Abstract Function level, identify the process values and components which affect that relation.

Example: Mass flow through the feedwater system

Functionally linked values: Water flow through the feedwater system
Storage tank, Feedwater pump

2. Movements Upward in Reasoning: "Why" Task: Given a component identify the process(es) and function(s) it impacts.

Example: Feedwater pump

Functionally linked values: water flow through the feedwater system
pressure increase in the feedwater system
mass flow through the feedwater system

Components or function values will be presented randomly and the subjects will be asked to click and highlight all the values and components they feel are functionally related to the target component or value. Subjects will be discouraged from indicating topologically related components.

5. Fault Detection and Diagnosis - The subjects will be presented with several fault scenarios which will be presented in real-time. The fault scenarios will be intermixed with normal scenarios. The normal scenarios will demonstrate small transients. The reason for including normal scenarios is to prevent the subjects from anticipating the fault scenarios and responding precipitously to random fluctuations in the presented information. Some of the faults will consist of the faults used in the training session but there will be unanticipated faults as well. It is proposed that the ratio of unanticipated faults to training faults = 2:1. The order of presentation of the faults will be randomized for each subject. In some of the faults automatic systems will take action to compensate for the fault.

The following is an example of a typical scenario (Hollender, personal communication Oct. 2, 1996).

- *Main Feedwater pump fails*

-*Plant power MKA00CE006 increases from 600 MW to 750 MW*

- *after 2.5 min. the main feedwater pump (seems LAC01) trips,*

- *after another 10s auxilliary feedwater pumps LAC02 and LAC03 take over*

- *after another 40s the Boiler chamber protection system activates because HAD31CT002 > 425 Cel*

Subjects will be asked to respond:

1. when they first detect a fault

2. when they feel they can diagnose the fault at a component level

3. when they detect a compensatory action from the system at a component level

Following the completion of the scenario the subjects will be asked to describe as fully as possible what occurred in the scenario.

5. Compensation - The subjects will be compensated on an hourly basis at the prevailing rate. A bonus will be offered to the subject with the most correct diagnoses in the shortest amount of time in order to provide incentive for correct and timely diagnoses. To encourage subjects to complete the experiment there will also be a bonus for completion of the experiment.

Apparatus. The experiments will be conducted on a Dell PC compatible microcomputer with a 133 MHz Pentium processor, a 2 MB video card. The plant simulation is the M5 simulation of an 750 MW ABB conventional power plant and contains 176 simulated plant variables. The interface will be designed using Intellution Fix v6.0 in a Windows-NT environment. Intellution Fix contains historical data-logging functions which should aid in the data collection.

Data Collection. The following data will be collected during the experimental tasks.

1. Steady State Tasks

a. time to complete task

b. components/values identified

c. screen manipulations made

- display changes

- zooming actions

- panning actions

d. order of identifying components and process values.

e. verbal protocol

2. Fault Detection Tasks

a. screen manipulations made

b. time to detect fault

c. time to diagnose fault

d. time to detect a compensatory system action

e. description of scenario

f. verbal protocol.

If feasible, data will be collected using the historical logging features of Fix. This has yet to be confirmed. If this is not possible, the data will be collected using video. Detection and diagnosis of the faults will be conducted on line so that the responses are made immediately.

Performance Measures. From the data collected, the following measures will be used to assess the performance of the subjects in the various conditions.

1. Steady State Tasks

a. Correctness and Completeness of Solutions:

The correctness of the solutions offered will be evaluated. The percentage of correctly identified components and values at each of the functional levels will be calculated. Also the number of unrelated components and values that are included will be measured. “Why” tasks and “How” tasks will be examined for differences in performance between the two classes of tasks.

b. Trajectories of Solutions:

The order of identification of the components and values will be recorded and mapped against the abstraction hierarchy of the system. This should provide some basic trajectories through the abstraction space. Trajectories will be examined for distance and deviation from the most direct trajectory, the diagonal. The purpose of these measures is to examine the strategies used by the subjects and to determine whether or not the different interface conditions are affecting these strategies.

c. Trajectories through Displays

Paths through the displays will be mapped and display actions taken measured. The trajectories through the display space are important to measure in order to ascertain any differences between the interface styles as well as to look for ineffective interface design that causes disorientation or problems such as display thrashing mentioned by other researchers (Elm & Woods, 1985; Eastman, Woods, & Elm, 1986; Woods, Roth, Stubler, & Mumaw, 1990). It is expected that the more integrated displays will require fewer display changing actions though possibly more panning and zooming actions.

d. Information Management Measures

- Dwell Time: The time spent on each display, "dwell time" will be calculated. It is expected that the more integrated displays will have a higher dwell time since more information is available and fewer display changes must be made.

- Visible Information Measures:

Total information available: From the zooming and panning actions, the number of visible display variables at each functional level will be measured.

Relative Keyhole Size: # of display variables/ total # of possible display variables.

Relative Occludedness: 1- keyhole size.

Absolute Keyhole Size: the number of displayed variables

Absolute Occludedness: the number of undisplayed variables

2. Fault Detection Tasks

a. Time Measures: The basic time measures will be:

Time to Detect = Time elapsed from the start of the fault until the subject indicates that they have detected a fault.

Time to Diagnose = Time elapsed from the start of the fault to the indication that the subject has diagnosed the fault.

Time to Detect a Compensatory Action - Time elapsed from the start of a compensatory action until the subject indicates that they have detected a compensatory action.

These measures are typical of detection and diagnosis studies (cf. Sassen, et al., 1994).

b. Accuracy Measures

The accuracy of the diagnosis made will be evaluated. As well, faulty diagnoses, and false alarms will be measured. Vicente et al. (1995) and Vicente et al. (1996) will be used as models for eliciting and evaluating the diagnoses.

c. Trajectories through Displays will be measured as in the steady state tasks.

d. Information Management Measures will be measured as in the steady state tasks.

Representativeness - Strengths and Weaknesses. In order to assess the generalizability of the findings which may be obtained from this experiment, it is worthwhile to consider a priori the strengths and weaknesses of this study. One of the strongest aspects of this study is that it uses a fairly complete simulation of a conventional power plant. At the component level there are 176 simulated plant variables and this is quite an extensive simulation (cf. Sassen et al., 1994). The prototyping tool being used for developing the displays is an industrial prototyping tool. Both the tool and hardware platform were suggested by ABB in order to be consistent with their current research display efforts. Certain conditions of the displays are very close to what is being implemented in industry. ABB's current interface contains several different levels of functional information but the levels are isolated and not integrated. This is similar to the conditions being examined as condition IV. Westinghouse is currently implementing a 2 window system with physical and functional information in separate windows. Condition II is a simplification of this design.

A weakness of this study is that it involves mechanical engineering students instead of real operators. It is unclear how well mechanical engineering students will be able to apply their thermodynamics knowledge in a more operational setting. Previous studies have found this to be problematic (e.g. Vicente et al, 1996). Generalizability to real operators should not necessarily be assumed because of the differences between theoretical and operational knowledge. Another weakness is that the system simulation is not controllable at this stage, limiting this study to detection and diagnosis tasks. As well, being a simulation, there are some aspects of realism, which will be missing.

Contributions of this work.

1. Design Contributions: This project is the first study and first implementation of 4 levels of abstract information for a complete conventional power plant using a fairly complete simulation. Toshiba has implemented Abstract Function and Generalized Process Displays for a simulated BWR (Itoh, Sakuma, & Monta, 1995). Sassen et. al. (1994) have implemented Abstract Function displays for a generic nuclear plant simulation with 74 plant variables.

2. Human Factors and Engineering Research Contributions: This is a study of interface design problems which arise out of having to design interfaces for large complex systems, an area which has not received alot of attention in the literature. In particular, this research addresses one of the potential cognitive difficulties of providing large information spaces on limited computer hardware; that is, the difficulty of maintaining functional link knowledge as functional levels become isolated.

The initial results of applying functional information to small scale systems have been promising but many of the issues involved in applying these ideas to larger scale systems need to be investigated. In particular, it has been argued occasionally that there is a potential trade-off between gains from adding functional information and losses from added visual clutter. This research addresses and searches for this trade-off point.

As well, this research investigates one of Wood's proposed techniques for improving visual momentum to assess its contribution in reinforcing functional link information.

3. Exploration of other design-relevant directions: Some further lines of exploration are already apparent:

1. Experiment with Control

When operator control over the ABB simulation is possible, this experiment could be repeated. If similar results were obtained this would strengthen the previous results by showing that any performance gains demonstrated were applicable to control and operation as well as to the fault detection scenario.

2. Exploring other visual momentum techniques

There are several other visual momentum techniques proposed by Woods (1984) which could be investigated using this framework.

3. Exploring different parsings.

A functional parsing of [1] [2,3,4] would be worthwhile investigating comparatively. This is the parsing being used in the Westinghouse Advanced Control Room.

4. Controlled investigation of the keyhole effect.

The keyhole effect is a prevalent phenomenon in the computerized display of large and complex systems. This computer simulation and prototyping environment would provide a good opportunity for investigation of this phenomenon.

<u>Status Report</u>

TASKS

1. Background reading

Determination of experimental measures

Background reading will consist of readings in the perceptual control of navigation, locomotion through information fields, and navigation issues in interface design.

Experimental measures will be drawn from traditional interface navigation measures, information retrieval measures, and field theoretic measures.

Time frame: Jan 96 - May 96

Inputs required: literature and discussions

Contacts: Kim Vicente, Bob Shaw, Endre Kadar, Mark Chignell

Product: chapter of the final report summarizing the literature and the potential use of different measures

Status: A literature review of the above areas has been performed and ideas on navigation issues and possible experimental measures have been extracted. A summary of the literature has been written and is included in this final report.

Work remaining: None. Incorporation of any recent findings only.

2. Correction and Confirmation of MFM based displays

The MFM displays proposed last year will be reworked specifically for the ABB conventional power plant. In addition, a deeper knowledge of MFM modeling techniques will be obtained and this knowledge will be used to correct and improve the MFM display ideas.

Time frame: March 96 - June 96

Inputs required: MFM literature, ABB system information, 95 display ideas

Contacts: ABB, Professor Morten Lind (Technical University of Denmark)

Products: 1. MFM models of the ABB conventional power plant (figures)

2. chapter of the final report summarizing the use of MFM and the development of the models in 1.

3. reworked MFM display concepts. (figures)

Status: The MFM models were reworked and confirmed with Morten Lind. The MFM models have been described and included in the final report.

Work remaining: None. At the present time, MFM displays do not seem to be a promising direction. There are no plans to implement any MFM displays.

3. Correction and Confirmation of the Rankine Cycle based displays

The Rankine cycle based displays will be reworked specifically for the ABB conventional power plant.

Time frame: May - June 96

Inputs required: ABB system information, thermodynamics

Contacts: ABB, someone in Mechanical Engineering

Products: 1. chapter of the final report describing the development of the Rankine cycle based displays

2. reworked Rankine cycle display concepts (figures)

Status: We have established Dr. Susan McCahan as an advisor on the Rankine cycle displays. Software for plotting the saturation curve on the temperature-entropy plane has been obtained as has software for modeling different plant configurations.

Work remaining: None. A temperature-entropy plot based on values from the ABB simulator has been developed directly in Fix.

4. Investigation of Alternative Prototyping Environments

Intellution's Fix will be investigated as well as any other prototyping environments proposed by ABB.

Time frame: April 96 - ?

Revised Time frame: April 96 - September 96

Reason: Delays involved in purchasing a new computer and solving Fix version problems.

Inputs required: initial contacts with software companies

Contacts: from ABB

Products: email discussion of investigations and decisions on prototyping environment

Status: A computer capable of running Fix was purchased and arrived in mid-August. There were some compatibility problems between the ABB version of Fix and the demo version our Intellution distributor gave us. These were resolved by receiving ABB's version of Fix directly. The simulator is installed and running. The Fix environment seems powerful and easy to use.

Work remaining: None.

5. Experimental Outline

The specific experimental questions will be detailed. Determination will be made of the display prototypes required and the general approach to be followed.

Time frame: June 96- July 96

Revised Time Frame: Sept 96 - Oct 96

Reason: Revision of #4.

Inputs required: experimental guidance, approval by ABB of display concepts from #3 and #4, detailed information from ABB on the protocol of the MDD experiments

Contacts: ABB, Kim

Products:
1. chapter of the final report outlining the experimental protocol
2. a list of the displays which will be prototyped.
3. figures of the display suite architectures which will be prototyped.

Status: A proposal has been prepared and is included in this final report. The direction being pursued is the use of display overlap to provide integration and visual momentum between different functional levels.

Work remaining: None.

6. "Dead" Prototypes

Display screens will be drawn in the prototyping environment.

Time frame: July 96 (may take longer if prototyping tool changes)

Inputs required: ABB approval of #5, prototyping tool

Contacts: Nick Dinadis for Vaps (if that is the tool)

Products: 1. display pages

2. working navigation tools

Status: Given the nature of the Fix environment and the ease of connection with the ABB simulator, there seems to be no need to differentiate these prototyping stages.

Work remaining: None.

7. "Live" Prototypes

Display screens will be connected to the ABB simulator or made able to run off ABB simulator files.

Time frame: August 96

Revised Time Frame: Sept 96 - Nov 96

Reason: dependent on development of proposal

Inputs required: ABB simulator information and data, ABB approval of #6

Contacts: ABB

Products: 1. working display pages

Status: The first iteration of the Physical Function and Generalized Function displays is completed. Minor changes are expected.

Work remaining: Abstract Function and Functional Purpose displays remain to be prototyped. As well, the exact experimental displays have not been constructed.

8. Experimentation

Following the protocol in #5 and the measures from #1.

Time frame: following #7, dependent on the experiment design

Inputs required: TBD

Contacts: TBD

Products: raw data

Status: Not started.

9. Data Analysis

Time frame: after #8

Inputs required: TBD

Contacts: TBD

Products: results section of final report

Status: Not started.

10. Preparation of Final Report

Time frame: Nov 96

Inputs required: TBD

Contacts: TBD

Product: Final report due Dec 1, 1996

Status: Completed.

Planned work

The following is a list of tasks expected to be completed in 1997.

1. Confirmation and Modification of Experimental Proposal

Time frame: Dec 96

Inputs required: Feedback from ABB and advisory committee at UofT

Product: Revised Proposal

2. Prototyping of Experimental Displays

Time frame: Dec 96

Inputs required: Approval of experimental proposal

Product: Fix prototypes

3. Pilot Test

Time frame: Jan 97

Inputs required: Experimental scenarios from ABB

Product: Pilot data

4. Revision of Experiment based on Pilot Test

Time frame: Jan 97

Inputs required: Pilot test results and experiences

Product: Revised experimental plan

5. Data Collection from Experiment

Time frame: Feb - April 97

Inputs required:

Product: Experimental data

6. Data Analysis from Experiment

Time frame: May 97 - Sept 97

Inputs required: Experimental data

Product: Analyses

7. Final Report

Time frame: following 6

Product: Final report detailing experimental results and conclusions

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