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A participant-observer study of ergonomics in engineering design: how constraints drive design process

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Abstract

Too often, ergonomics is relegated to being a "post-design" evaluation, leaving ergonomists little opportunity to make significant and important design changes. One way to start attacking this problem is to study the process of design and, in particular, ergonomics in design. This article describes the findings from a four-month long participant-observer study of the relationship between ergonomics and engineering design. The study was conducted in the context of a large, interdisciplinary project consisting of design of a control room for a nuclear power plant. It was observed that designers and ergonomists must negotiate through a changing web of constraints from many sources. The impact that these constraints had on the course of the design was documented. A model is developed based on the abstraction hierarchy (Rasmussen, 1985, IEEE Trans. Systems Man Cybernet. SMC-15, 234–243; 1990, Int. J. Ind. Ergon. 5, 5–16) which shows the interaction of conflicting goals as ergonomists and other designers attempt to solve a complex design problem. This model leads to several insights: (1) locally optimal ergonomic designs may not be globally optimal, (2) ergonomists can improve their solutions by understanding the goals of other designers, and (3) future tools to aid ergonomists must be compatible with the constraint-rich environments in which they work.

Keywords: Engineering design; Field study; Constraints; Design process; Human factors

1. Introduction

The study of the relationship between ergonomics and engineering design is of the utmost importance. For many years, ergonomists have complained that ergonomic factors frequently get left out of the design process. Consequently, the products that are designed are not nearly as useful or usable as they might otherwise be. If we are to rectify this situation, then we need to understand the constraints that govern engineering design projects and how those constraints impact the consideration of ergonomic design features. Otherwise, ergonomics will continue to be a second-class citizen in the world of engineering design.

Given the importance of this issue, one might think that a great deal of research would have been conducted on this topic. Unfortunately, studies of the relationship between ergonomics and engineering design are comparatively rare. This is not to say that the issue has not been addressed at all. For example, Meister and Farr (1967) conducted a seminal experiment to determine how designers utilize ergonomic information, and also provided new information on the design process, noting that designers work "from the outside in", or from large-scale details to finer details. Klein and Brezovic (1986) conducted an interview study to determine how expert designers make decisions, and found that they recognize typical design situations and quickly make decisions based on this design experience. Also, Rouse and colleagues conducted numerous studies of the relationship between ergonomics and engineering design (e.g., Rouse and Cody, 1988,1989; Rouse et al., 1991). More recently, Wulff et al. (1994) conducted a revealing study of the role of ergonomics in a large-scale engineering design project.

All of these studies have provided very valuable insights but they have limitations which need to be addressed. Most of the studies point to the problem in the relationship between design and ergonomics, but are not

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specific enough to understand the problem as deeply as required to begin to recommend solutions. Research in this area is also limited by the fact that comparatively few studies have been conducted on a continuous basis in the field. Most studies have either involved experiments (e.g., Meister and Farr, 1967) or interviews with designers (e.g., Klein and Brezovic, 1986). Therefore, although contributing to knowledge of design processes in practice, these studies do not fill in the fine details of what occurs. A deeper understanding of design is required.

To counter this problem, we decided to study ergonomic design in depth and in situ. We chose the approach of participant-observation (Meyer, 1992), from the field of ethnography, to get daily access to process details and participants. Rather than sparsely sample from several situations, we spent every weekday over four months involved with a single project. We chose to participate in the design of a control room for a nuclear power plant because the project was large and complex enough to permit observations of the interactions of ergonomists with other designers. In addition, the nuclear power industry strives to include ergonomics in its design process due to the safety-critical nature of the domain. If anything, this domain would give us an optimistic view of ergonomics in design. As far as we know, this is the first study in the literature investigating the relationship between ergonomics and engineering design in the nuclear industry.

In the following sections, we describe our methodology. Because our methodological choice was somewhat unusual for the field of ergonomics, we have described it in detail. Instead of a results section, we have substituted a situation description. The situation description provides a summary of the context of the design process we observed. Next, we describe in detail a specific example, discussing micro-events that happened in this part of the design. Finally, we discuss the insights drawn from this study as a whole. This discussion is oriented at taking a detailed look at why ergonomic design is not always adopted.

2. Method

The participant-observer methodology (Meyer, 1992) allowed us to obtain access to daily engineering events and to gain an intimate understanding of the constraints ergonomists face and the ramifications of those constraints on their design process and design results. The position of the participant-observer (p-o) was as an ergonomic consultant in the company's that man-machine design department. Observations were made on a daily basis, for the normal range of working hours, over a four-month period. The p-o was given access to all people and resources needed to complete the project and participated in design meetings. In all, 677 hours were spent at the field site, 28.5 of these hours in design meetings.

Observations were logged unobtrusively while at the field site, and daily summaries of events were made. These observations and notes constituted the raw data of this study.

The project, expected to take several years, was observed in its early design stages, shortly after the award of the contract. This timing was an unexpected bonus, since these are the design stages that are most sensitive to new ideas and concepts. The next section provides more detail on the design situation.

3. Situation description

In this section, we describe the context in which the design project was taking place. To organize the description better, we have used several categories. To describe the project, we have discussed the size of project, the available resources, and the rate of change of technology in this industry. To explain some of the unique challenges these designers were facing, we have described their access to design expertise, the degree of separation between involved parties, and the degree of regulation they had to meet. Finally, we have described the design tasks to be accomplished, and, more specifically, the ergonomics responsibilities. It would be impossible to describe every detail of the situation, but the categories we chose provide a broad coverage of the context of the design.

3.1. *Size of project*

This was a large project. The design work was distributed over many designers from different departments and backgrounds, although predominantly from engineering. To give an idea of the magnitude, the entire project was distributed over approximately 19 departments and involved 150 people. Geographically, most of the designers were located at a single site although some designers, management, and resources were located at a different, yet nearby building. For this specific project, designers had been regrouped into project-oriented departments resulting in a temporary matrix-style organizational structure (Robbins, 1990).

3.2. *Resources*

There was a variety of resources ranging from microcomputers to full-scope simulators. Designers were experienced and the company itself had a long history of design experience. Many areas of the nuclear industry are relatively mature with extensive related research and evaluation of design, but some areas, like advanced control room design and design for hybrid control rooms, are still developing. The industry is subject to extensive regulation and adherence to regulation and standards is a compulsory part of every project, standards usually being specified at the contract stage.

3.3. Rate of change of technology in the industry

Rate of technology change varies. For example, the fundamentals of a nuclear reactor have changed very little, yet automatic control and protection systems have progressed rapidly. In control rooms, dedicated hand-activated controls have been used for years, yet there is a push to begin to introduce computerized systems for both monitoring and control. Despite this push, however, safety concerns about computer system failures are resulting in the design of hybrid control rooms consisting of computerized interfaces but keeping dedicated controls for safety-critical functions. This control room was to be one of these hybrid control rooms. New materials used to construct the panel and control room are more flexible and easier to manufacture than older materials. Computer technologies provided many device options for controls and inputs.

3.4. Access to design expertise

In general, designers and project leads had worked on several previous projects. There were also in-house resources such as an internal ergonomics research division. Previous designs were available, if needed. Designers had access to reports and guidelines in the industry. These designers, however, had never before designed a control room for this kind of plant, and had never before designed a hybrid control room.

3.5. Degree of separation between involved parties

This particular project had an added twist in that the customer was a foreign utility, separated by geography, language, culture, and technological environment. Designers had to work with the plant that was already partially built and that was substantially different from North American designs. As well, North American design ideas, for example in graphical displays, were undoubtedly novel to the utility.

3.6. Degree of regulation

In this case, the company had agreed to meet regulatory requirements both in the country of design and in the country in which the plant was to be located. Regulations affected different design parties in different ways. For example, standup panels and safety critical equipment had to meet seismic qualification. The ergonomic aspects of the control room were contracted to meet IEC-964 (International Electrotechnical Commission, IEC, 1989), a voluntary international standard for the design of control rooms for power plants that specifies both ergonomics design criteria and design process.

3.7. Design tasks

The design tasks of this particular project were a bit unusual. The contracting utility had already built the reactor and the buildings to house the control room. The control room designers, therefore, had to design a control room for an already existing plant, with consideration of the sensors and actuators that were present. Functional information, however, was largely lacking. For example, it would be known from plant drawings that a certain feedwater stream had x number of valves of which some were manually controllable. Functionally, however, it would not be known what purpose that feedwater stream served. In many cases, engineers had to infer design purposes from the drawings. For the most part, the plant was "wired" already, meaning that sensors and their signals already existed. In particular, the level of automation of plant systems was pre-determined. In addition, the control room itself had to fit within the existing space allotted for the control room, with walls, doors, and basic wiring in fixed locations.

3.8. Ergonomics responsibilities in the project

There were several aspects of the design that required input from ergonomists. A task analysis was to be performed. Control boards had to be designed and laid out. Furthermore, the indicators and controls to be put on that board had to be selected or designed. This was to be a hybrid control room, that is, a control room containing both hard wired and soft controls. This meant that soft displays and controls also had to be designed.

The goal of this section was to describe the general design situation, that is, the elements of context that are unique to this particular project. In order to illustrate this process, the next section describes part of the design problem itself, the original design, and design changes that were made to the control room panel.

4. Specific design example

For a specific design example, we have extracted the design of the general size and shape of the standup panels for the control room. This design problem involved many designers, and several design changes occurred during the period over which we observed the project. For this reason, this example is rich enough to allow us to discuss the fine details of design process. Fig. 1 shows the development of this design along a four-month timeline.

Standup panels are the large panels typically located along the walls of a control room on which meters and controls and alarms are placed. When the field study began, an initial design of the panel profile already existed. For ergonomists, one of the main concerns is that controls and meters are readable and reachable. Therefore, this first design was based on anthropometric data provided in the standard IEC-964. Further work with this data set refined the design of the panel. The analysis was then documented.

The data used from the international standard, however, was drawn from an American population. Two months later, specific anthropometric data for the customer's population were received from the customer. This population's dimensions were somewhat smaller than the IEC-964 data. Accommodating this new data set would have required redesigning the control panels to be shorter by about 1 in (2.54 cm). The changes were considered to be insignificant and were noted but not made.

Two weeks later, it was discovered that the current panels would not fit through the hallways of the building, as designed. For shipping purposes, the panels had to be resegmented. The panels were redesigned so that they could be segmented and shipped through the hallways of the building.

Near the end of August, a design document was issued to the customer illustrating the panel designs. The customer felt that the panels "looked too small" and, upon learning that the panels were designed to meet anthropometric criteria, established a minimum height requirement for their operators, thereby cutting off the lower end of the anthropometric data set. The panels were then redesigned to be taller.

The final change observed during the field study occurred due to a manufacturing consideration. It was decided that the panels would be constructed from mosaic material – a modular construction of small blocks covered with plastic that would give flexibility in layout as it would permit modifications to be made. The material, although it could be cut, came in fixed sizes, one of which was just slightly larger than the size of the board. To make the manufacture of the panels easier and cheaper, the board was extended once again (Fig. 1).

As illustrated in the example, many practical changes happen during the course of a design. Although ergonomists may strive for the optimal ergonomic design, there are constraints that prevent the locally optimal ergonomic design from being a globally optimal solution for the design problem.

5. Discussion: why the best ergonomic design is not always adopted

To explore in more detail the effects of the constraints on design, we have broken them into several categories. These are not the only possible categories, but these categories were derived from an examination of the particular design problem that was observed. The categories, however, are general, and will apply to some degree in many design projects. *Contextual constraints* are constraints that arise directly from the design problem and are one of the most obvious sources of constraint on a design. Large projects, however, are also subject to *constraints of parsing and distribution*, which arise due to the way in which these projects must be managed. Projects are divided into subtasks, and unfortunately these divisions are artificial and create problems of their own. Because these projects are so large, they must, of

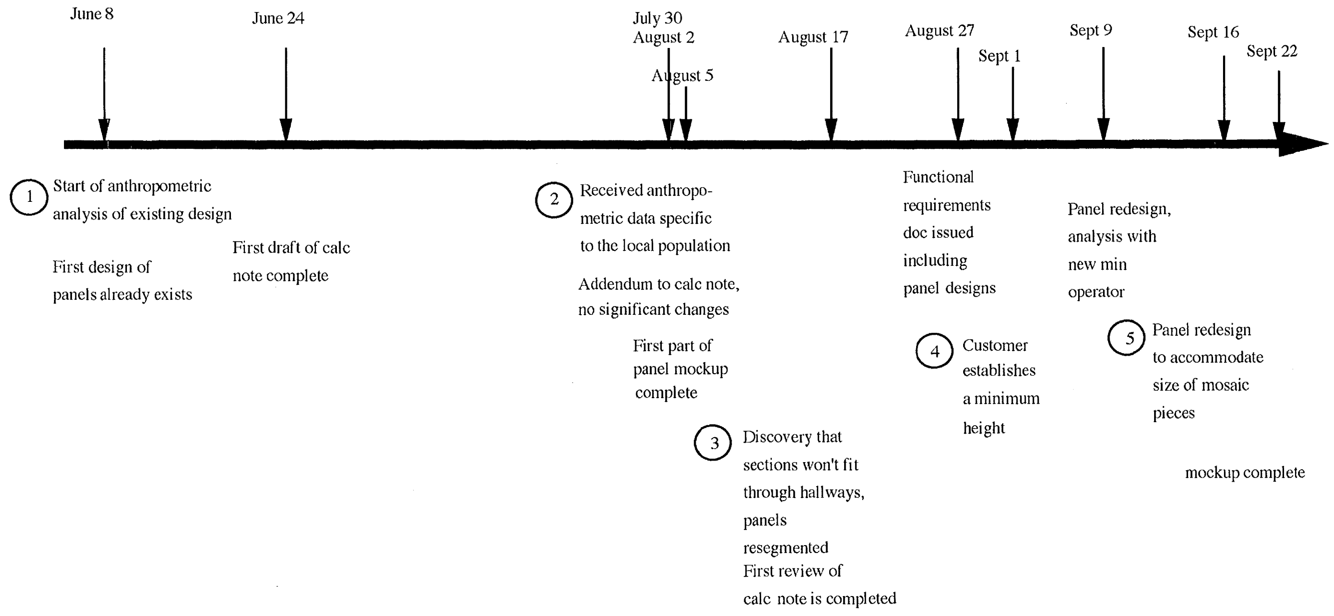


Fig. 1. Panel design changes over 4 months.

necessity, be divided across many designers with different sources of expertise. This creates a third source of constraint, *constraints from other domains*. In the following discussion, we will demonstrate how these different types of constraints impacted the design process, and the ultimate design solution that was reached.

5.1. Contextual constraints

Contextual constraints arise from the design environment. Most sources of contextual constraints were described in the situation description, earlier. A strong example of a contextual constraint influencing the design in the example were the dimensions of the hallways – a pre-existing contextual constraint. Any design solution that did not consider those dimensions was not feasible. Therefore, when the proposed design did not accommodate the hallway size, the design had to be changed.

Another example of a contextual constraint were the anthropometric data of the population. When the data for the actual population were not available, designers sufficed with data from another population. But when this constraint changed, through the arrival of new data, ergonomists had to consider the impact of this revised constraint. In this case, the impact of the constraint on the design was not thought to be significant and the design did not have to be changed to accommodate it.

5.2. Constraints from parsing and distribution

On a large design problem that is taking place over a long period time, the design problem is inevitably broken up into subproblems and distributed across different designers according to their expertise. While this is a sensible management approach, it creates a set of constraints that arise from the parsing of the design problem. To demonstrate this, and recalling the ergonomics responsibilities that were outlined in the situation description, the ergonomics subproblems are shown in Fig. 2. It will become apparent that these subproblems constrain and impact each other. For example, consider the following example that occurred in this design project.

Subproblem 1: *Control board size.* When designing the control board, designers must consider how much space is needed to accommodate the hard-wired meters and controls for the plant. In this project, however, control boards were designed before the hard-wired meters and controls were chosen.

Subproblem 2: *Hard controls and meters design.* These choices were being addressed after the size of the control panels had been determined. Controls and displays would have to be chosen so that they would fit on a limited board size and so that they would fit with the mosaic surface chosen for the control board.

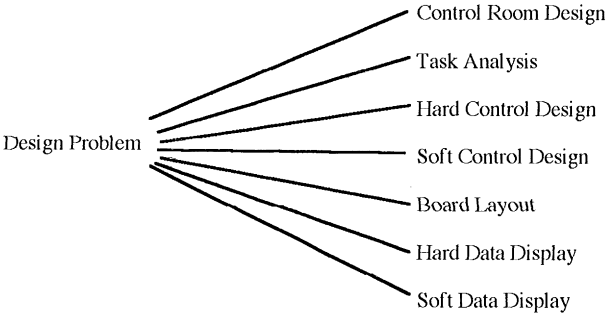


Fig. 2. Breakdown of control room ergonomic design into smaller problems.

Subproblem 3: *Hard and soft data display.* A decision to not display some information on a dedicated indicator may mean that information must now be displayed by the computer system. Conversely, a decision to display a parameter on the computer system as well may influence the choice of the meter or indicator that is used in the dedicated implementation. If we look at all the ergonomics subproblems, the situation is even more complex. As part of this study, we kept track of the interconnections between the different subproblems and have shown them in Fig. 3. Clearly, each subproblem affects a great number of other aspects of the design. A design decision made in one subproblem cascades through, creating constraints in other design problems that were not there when the project began.

A designer making a change, however simple, in one part of the problem is affecting a much larger sphere of the design problem. In combination with these effects, the interdependent nature of design leads to an iterative process. Not only are the outputs from part A critical inputs to part B, but the outputs from part B can be critical inputs to part A. A designer working on part A while part B is still being designed must deal with the uncertainties inherent in B's incompletion. In addition, as designer A works he is simultaneously changing B's design problem; as designer B works, she is changing A's design problem.

These interconstraints force iteration between interconnected design subproblems. In the meantime, however, global constraints can be affecting the total problem as well. The next section explores how designers from other domains impact the ergonomic design.

5.3. Constraints from other domains

In interdisciplinary design, designers must also satisfy constraints from other design domains. Although we were observing the ergonomists, it often seemed that many of the design changes had little to do with ergonomics. So where were the changes coming from, and what impact were they having on the ergonomic design of this control panel?

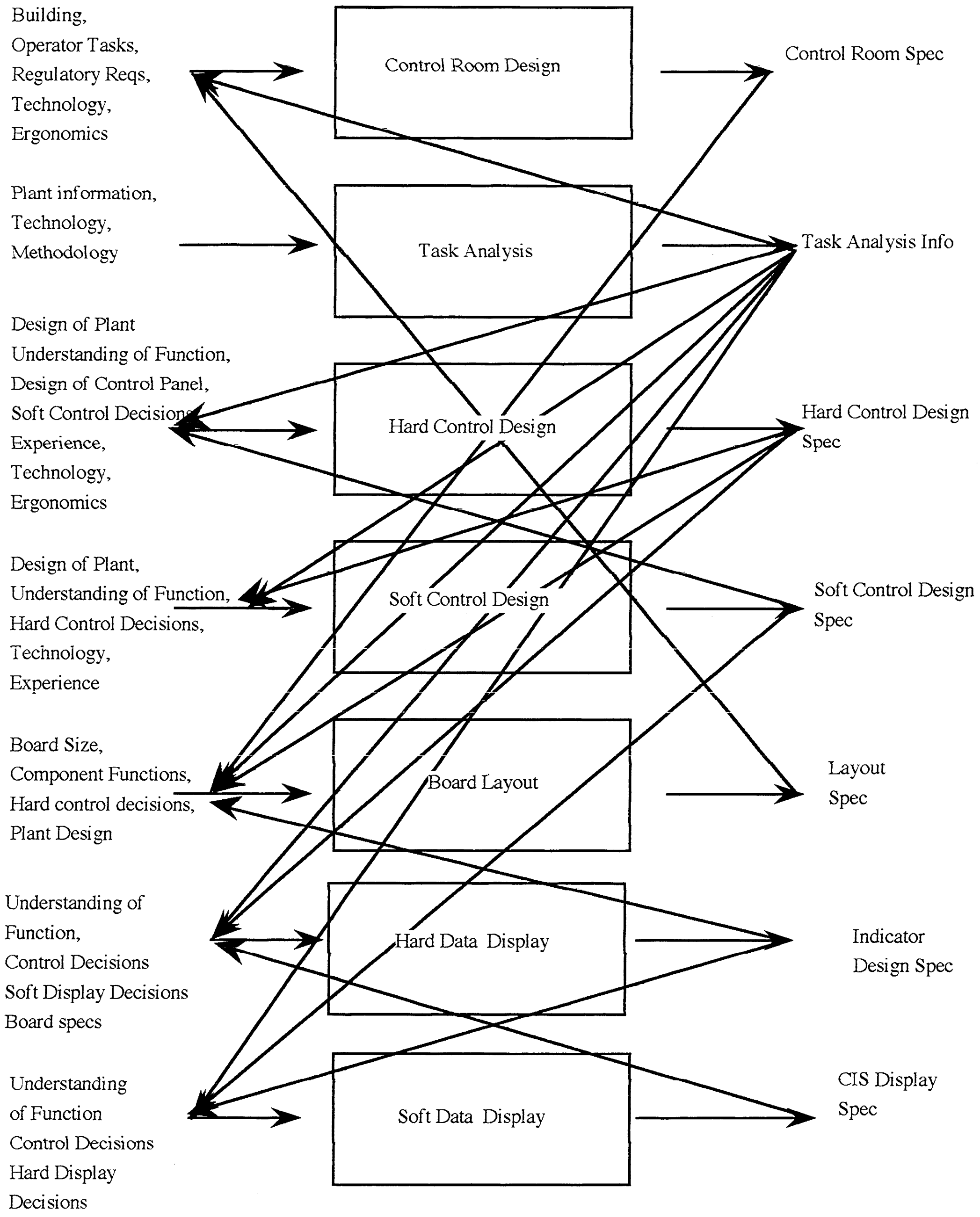


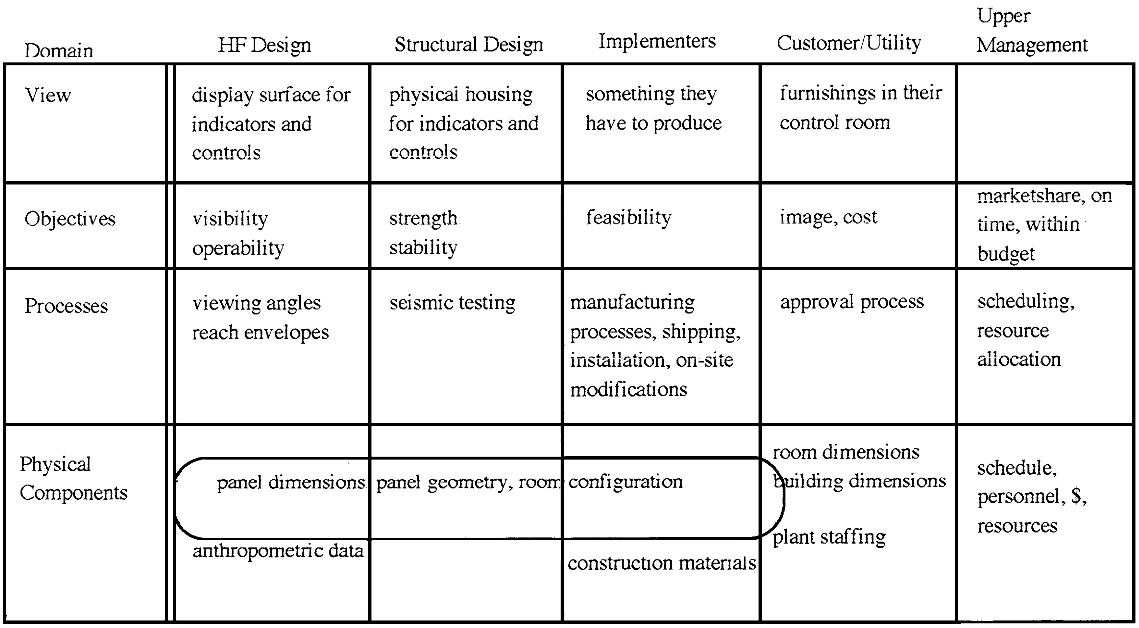
Fig. 3. Interdependent subproblems.

To examine design changes in terms of the different design parties, the two-dimensional constraint space shown in Fig. 4 was created. This constraint space is based directly on the abstraction hierarchy representation framework developed by Rasmussen (1985). Vertically, the space is divided into levels of abstraction. Horizontally, different domains involved in the design problem are represented.

5.3.1. Different domains

In a large design project, design tasks and responsibilities are divided across many people. These people have different goals for the design project and bring different perspectives when solving the design problem. Groups of designers that share similar views and goals can be considered as design parties or domains (cf. Schön, 1988; Bucciarelli, 1988; Rasmussen, 1990). In this case, the domains were defined as follows:

1. Ergonomics design – the members of the ergonomics design team.
2. Structural design – designers responsible for physically detailing the panel, choosing materials, manufacturers, and ensuring that the panels will be of



Domain	HF Design	Structural Design	Implementers	Customer/Utility	Upper Management
View	display surface for indicators and controls	physical housing for indicators and controls	something they have to produce	furnishings in their control room	
Objectives	visibility operability	strength stability	feasibility	image, cost	marketshare, on time, within budget
Processes	viewing angles reach envelopes	seismic testing	manufacturing processes, shipping, installation, on-site modifications	approval process	scheduling, resource allocation
Physical Components	panel dimensions anthropometric data	panel geometry, room	configuration construction materials	room dimensions building dimensions plant staffing	schedule, personnel, $, resources

Fig. 4. Two dimensional constraint space for this problem. This figure is copyrighted by the ACM and reproduced with their permission.

adequate strength and meet structural requirements such as seismic qualification.

3. Implementers – in some cases, these may be the same people as the structural designers, but in this case the emphasis is on implementation concerns such as manufacture, shipping, and construction.
4. Customer – the party that initiates the project and ultimately decides if the product is satisfactory.
5. Management – Management has a pervasive effect on all the design groups.

Another party that very well could have been included in this diagram is the regulatory bodies. Again, in this case, the influence is not specific but pervasive. To keep things simpler, the concerns of the regulatory bodies are represented by design parties who must meet regulation requirements.

5.3.2. Levels of abstraction.

The constraint space is divided into three levels of abstraction: physical components, functional processes, and objectives. It is possible that in some cases a finer gradation of abstraction levels may be useful (Rasmussen, 1985,1990). The levels shown in this framework were chosen because they have been used before (Rouse and Cody, 1989) and were found to be useful in examining this design problem. The important qualities of the constraint levels are that they are clearly hierarchical along *means–ends relations* (Rasmussen, 1985), clearly differentiable, and relate directly to design constraints. The overall view of the design domain has also been added to show the different perspectives that different design domains may have of the same design problem.

5.3.2.1. Objectives. Objectives are the overall design goals, mission, and purposes of the different design domains.

5.3.2.2. Functional processes. In a design domain, the functional processes are usually substantiated in the tests and methods used by designers of that design domain. In many cases, these processes represent criteria by which the design is judged, to ensure that it is meeting the design goals.

5.3.2.3. Physical components. The physical component constraints include such things as the raw data sources that designers use and the physical materials, sizes, and shapes of the design solution itself. These are the most elemental constraints and, sometimes, are shared across design domains.

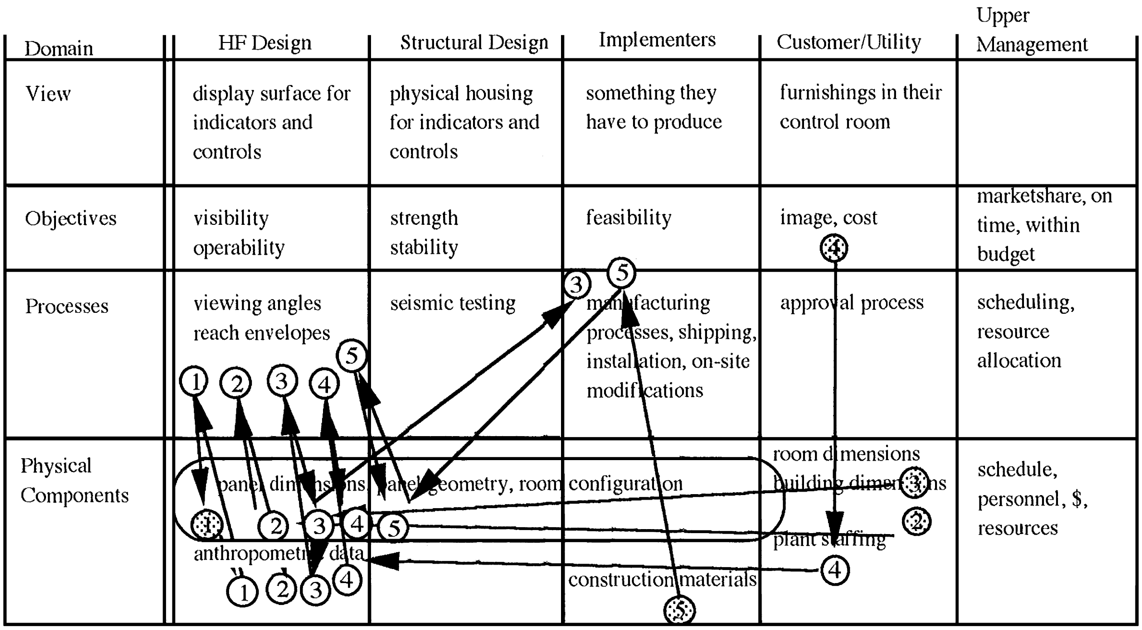
5.3.2.4. View of design problem. Each design domain has a different perspective on the design problem and approaches the solution differently. An ergonomist may view a console as a work space that must be comfortable and usable, whereas a structural console designer may view a console as a piece of furniture that must have a certain strength, rigidity, and lifetime of use. All of these views are correct, but only partial, views of the design solution.

5.3.2.5. Constraint satisfaction. The levels of abstraction and the breadth across domains create a two-dimensional constraint space for the design problem. For the design solution to be considered successful by any one party, it must satisfy their goals, successfully mesh with that group's functional processes, and be feasible in physical components. For the design solution to be considered successful in a global sense, it will have to satisfy the constraints of all of the represented domains.

To examine the effects of the constraints from different domains, the design activities associated with the panel example are traced across this space. The shaded circle in Fig. 5 represents the start of a series of activities.

1. The design cycle starts with a solution concept that specifies the initial dimensions and geometry of the panel, elements that are both at the physical components level. Anthropometric data are added and the design product is submitted to an ergonomics analysis, at the level of functional processes. Then, readjustments are made to the dimensions and geometry of the panel.
2. The second trace begins when the local anthropometric data appear from the utility. The anthropometric data set changes, subsequent changes in viewing angles and reach envelopes are calculated, and changes in panel dimensions are considered.
3. The third chain of events begins with the discovery of the hallway sizes. This information is compared with the current panel dimensions and a conflict with shipping and installation processes is seen. The panel dimensions are modified again. The ergonomics concerns are checked. The decision is made to resegment the panels, affecting their manufacture more than their design.
4. The fourth trace starts with a high level constraint on the part of the customer, "The panels look too small". At this point, the panel is meeting the constraint sets of the designers, as well as the lower level constraints of the customer. The option the customer takes is to manipulate one of their own lower level constraints – plant staffing – which sets up a "domino effect" (Fox, 1992). The anthropometric data set changes, the ergonomics analyses are performed again, and the panel is modified once more.
5. The fifth sequence begins with the choice of construction materials, namely the mosaic material selected for the panel. The larger size of the material indicates an expense in manufacturing processes. The designers check whether or not the panel size can be changed and agree to change the dimensions.

This analysis highlights several features of this design problem. Each design domain has a unique view of the design problem and will search for a solution that is consistent with this view. For the design solution to be successful though, it must be consistent with the views of all of the various design domains. One of the greatest barriers to successful interdisciplinary design is the inability of designers from different disciplines to understand and appreciate the different views of other design parties involved in the same project (Boff, 1987). When the customer objected to the ergonomic design in favor of a taller looking panel, a conflict in design views and objectives occurred. Ergonomics design, due to its interdisciplinary nature, is constantly exposed to these design conflicts.



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Physical Components	panel dimensions, panel geometry, room configuration anthropometric data		construction materials	room dimensions building dimensions plant staffing	schedule, personnel, $, resources

Fig. 5. Interaction of constraints across domains.

This analysis also provided understanding of design constraints. Within each domain, the design solution had to be acceptable at each level of constraint. At the highest constraint level, the objectives, vast differences were seen between the goals of the different domains. In contrast at the lowest level, that of physical components, many elements were shared. In this example, the customer and the ergonomists had different goals which resulted in a conflict over the height of the panel, a shared physical component. This situation, where design elements must meet the different objectives of different domains, is a classic source of design conflict. To reach a solution, the designers must not only satisfy their objectives but also negotiate their objectives with the objectives of the other parties.

This analysis also revealed the nature of the design process being observed – in the example seen here the design process was highly iterative with frequent repeated cycles of analysis. It was also observed that the design proceeded as sequences of activities initiated by changes in design constraints. Sometimes these changes originated at the physical components level; sometimes the design changes originated at the highest level of objectives. Changes in one domain forced reactionary design activities to occur in the other domains.

6. Conclusions

This work provides insight into why the "best" ergonomic design is not always adopted. The solution of a design problem is a negotiation of a constantly changing constraint field. Changes in contextual constraints change the required solution. A decision made at the beginning of the design project can change what solutions are feasible by the end of the project. Furthermore, ergonomists rarely work in isolation but must negotiate their design priorities with those of other designers so that the final solution is at least feasible from all perspectives.

Although the details may be unfamiliar, the general characteristics of the design problem described in this article will be very familiar to any practicing ergonomist. Contextual constraints provide the background for any ergonomics problem. Constraints arising from the parsing and distribution of design work are commonplace in large engineering design projects. And finally, constraints from other domains are inevitable in an interdisciplinary design effort. In fact, the characterization of design that emerges from this field study has much in common with accounts of engineering design that have been provided outside the ergonomics literature (e.g., Goel and Pirolli, 1992; Gero and Kumar, 1993; Schön, 1988; Bucciarelli, 1988; Gross et al., 1988).

In terms of using this knowledge of design process to leverage ergonomics into design, several implications are apparent. Ergonomists should have access to context-rich design examples that show how different constraints were satisfied to solve the design problem. Ergonomic guidance needs to be richer than laboratory results or guidelines. The true leverage points of design occur in the negotiation of contextual constraints, the making of wise decisions early in a project, and in negotiating ergonomic priorities with designers from other domains. The better ergonomists are at solving these design problems, the more impact they will have on the eventual design.

Our findings add another badly needed data point to the sparse database of studies investigating the relationship between ergonomics and engineering design. Moreover, because we adopted a participant-observer methodology, our findings do not suffer from the potential vagueness or memory biases associated with retrospective studies, such as those based on interviews (e.g., Klein and Brezovic, 1986). Some of these advantages can be seen in the concrete traces of design activity that we collected over four months.

Second, our findings (e.g., Fig. 4) also provide further evidence for the value of Rasmussen's (1985) abstraction hierarchy in understanding the relationship between ergonomics and engineering design (cf. Rouse and Cody, 1989; Rasmussen, 1990). Many authors have commented on the fact that ergonomists and other engineers frequently speak different languages, and hold different criteria (e.g., Haslegrave and Holmes, 1994). The abstraction hierarchy goes several steps further by trying to document the origin of these differences in an integrated framework, and by providing a systematic basis for understanding the conflicts and trade-offs that emerge as a result.

In addition to its descriptive value, the abstraction hierarchy framework also has potential pragmatic value. If we can identify the objectives of the various stakeholders in a design project, and determine how those differing objectives affect how the stakeholders each represent the same objects, then we may be in a position to create a decision support system to facilitate interdisciplinary cooperation. The abstraction hierarchy framework could represent these differing views and make them explicit rather than implicit. This should help other designers understand the needs of ergonomists. The abstraction hierarchy could also represent the connection between particular design data and multiple competing goals. This should provide a more informed basis for making the inevitable trade-offs that arise between ergonomics criteria and other design criteria. These possibilities are currently being explored in the Design Explorer project (Pejtersen et al., 1997), an international research program that is using the abstraction hierarchy as a basis for providing computer-based decision support to designers. The results that we have presented here suggest that such a tool may enhance the visibility, and thus the impact, of ergonomics in the engineering design process.

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