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JUDGEMENTS ABOUT THE VALUE AND COST OF HUMAN FACTORS INFORMATION IN DESIGN

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Abstract—This research investigated the criteria by which designers of human–machine systems evaluate design information. It has been suggested that information search behavior is governed by three attributes of the information being sought: perceived relevance, perceived importance, and perceived cost. These ideas were formalized and empirically evaluated with a questionnaire study. Professional designers of nuclear power plant control rooms were asked to rate hypothetical information search questions in terms of relevance, importance, cost, and effort. In the general results, the findings show that a linear additive model with either relevance, importance, or both, as predictors provides the best fit for the ratings of the majority of respondents. Looking at the individual respondents though, cost was often a significant predictor in addition to importance and relevance. The findings have important practical implications for increasing the utilization of information during design.

INTRODUCTION

Human factors design is concerned with the design of artifacts to be consistent with a human user's physical and psychological capabilities. As a result, human factors engineers are often responsible for applying the knowledge of human physiology and psychology in the design of objects and environments. In contrast, the human factors researcher is responsible for expanding the knowledge of human physical and psychological capabilities and transferring that knowledge to the human factors designer. In the field of human factors engineering, it has been noted that a gap exists between the worlds of the human factors researcher and the human factors designer (Vicente *et al.*, 1993). The problem is not that human factors information is not available to designers—in fact, human factors researchers have gone to great efforts to produce large compilations of human factors data and information for designers (e.g. Boff & Lincoln, 1988; Woodson *et al.*, 1992). But despite these efforts, human factors information has had very little impact on design (Vicente *et al.*, 1993). Recently, the trend has been to computerize these compilations of data (e.g. Monk *et al.*, 1992; Whitaker & Moroney, 1992) presumably, in the hope that the computerization will make the information more accessible and hence, used more often. But will this approach work?

With these concerns in mind, we explored the research that was available on the use of information by designers. We then took the prevailing ideas from this research and evaluated them with a group of highly experienced human factors designers of nuclear power plant control rooms. This paper focuses on the results of this evaluation and the lessons learned throughout this process.

BACKGROUND

There has been very little research examining the nature of human factors design and the transfer of human factors information to designers (Meister, 1985). It is no wonder then that human factors has had very little impact on design (see Vicente *et al.*, 1993 for a brief review).

Some notable exceptions to this generalization have been the work of Meister (Meister, 1985; Meister & Farr, 1967), and more recently, Rouse and his colleagues who, over the past decade or so, have conducted a number of studies of designers and of the design process itself (e.g. Cody *et al.*, 1993; Rouse, 1986; Rouse *et al.*, 1990, 1991). One of the early contributions of Rouse's (1986) research was an informal model of designers' information search criteria. Rouse concentrates on the "value" of information to designers and defines value as "what one is willing to pay in money and/or effort" (Rouse, 1986, p. 221). Rouse's ideas are concerned with the judgements made by designers at the earliest stages of information acquisition, namely: Will this information be valuable? Will it be hard to obtain? How hard am I going to try to get this information?

Rouse's work led to the following ideas:

(1) Designers' use of information is based on the perceived value of information and not on objective properties of the information (Rouse, 1986). Rouse elaborates that "the value of information . . . depends totally on the recipient's intentions and perceptions" (Rouse, 1986, p. 222).

(2) Information will only be accessed if its perceived value is greater than the perceived cost of obtaining it (Rouse *et al.*, 1990).

(3) Reduction of uncertainty, relevance, and appropriateness of form are dimensions affecting the perceived value of information (Rouse, 1986). By reduction of uncertainty, Rouse means "gaining knowledge of a previously unknown fact" (p. 221). By appropriateness of form, Rouse is referring to the magnitude of the transformation which must be applied to the information to make it usable.

(4) It is important to distinguish between information that is relevant and necessary and that which is relevant and discretionary. Design information that is relevant but discretionary can be ignored and the design problem can still be solved (Rouse, 1986).

(5) Almost all research literature falls in the category of discretionary (Rouse, 1986).

In the domain of information science, there is a substantial body of work examining the definition and use of relevance in information search. The main ideas from this work are that information relevance is a dynamic state depending on the user's perception of the information at a certain point in time (Schamber *et al.*, 1990). There has also been substantial work examining information search, search questions, and post-retrieval evaluation of information relevance (e.g. Saracevic & Kantor, 1991; Saracevic *et al.*, 1988; Smithson, 1994). Handbook providers, however, act as *intermediaries* in the information retrieval process (Vicente *et al.*, 1993) and must select information for their users that is as relevant as possible to as many users as possible. Ideally, this intermediate step in information retrieval should increase the importance and the relevance of the information and decrease the costs of obtaining it. For this to be successful though, handbook providers must understand what information is valuable to the users and how those users moderate their perceptions of the value of the information with their expectations of the cost of obtaining it. For this reason, this work concentrates on evaluating whether or not the information provided to human factors designers is relevant and important, and on exploring how human factors designers balance the perceived value of information with perceptions of the cost of obtaining it.

FORMALIZING THE IDEAS

This paper describes an exploration of these ideas. In order to do this, Rouse's ideas were slightly modified in order to produce a formal, testable model.

(1) To test "perceptions" of information by the "recipients" of that information it was necessary to test for information without revealing the actual details of the information. To accomplish this, we used questions that would likely require an information search in order to be answered. A human factors handbook, the Engineering Data Compendium (EDC) (Boff &

Table 1. Sample question and rating scales used in the questionnaire

With a constantly monitored display, is an increase or a decrease in parameter value detected sooner? skip __

Cost to obtain

No cost — High Cost

Importance

Not important — Indispensable

Relevance

Irrelevant — Highly Relevant

Effort you would spend

No effort — High Effort

Lincoln, 1988) contains a section called the Design Checklist which provides a collection of various questions that a designer might ask as an indexing tool for the handbook. These questions map directly on to information in the handbook and are intended to match with a designer's questions. Table 1 contains an example of the questions used. Note that subjects were never informed of the source of the questions.

To satisfy the second part of Rouse's idea, the recipients, we used professional human factors designers working on real projects—human factors designers of nuclear power plant control rooms. This also has the advantage of making our results more representative (Brunswik, 1956) and more likely to generalize to operational settings.

(2) To measure the perceived relevance of the information, we had the subjects rate the Relevance of the information asked for by each question taken from the EDC along a semantic differential scale.

Rouse's criterion of reduction of uncertainty was removed from direct consideration. Reduction of uncertainty was defined by Rouse as occurring if "one gains knowledge of a previously unknown or forgotten fact" (Rouse, 1986, p. 221). This study was limited to understanding the criteria for transferring previously unknown information to a designer. Although the precise facts of the information being used in the test of the model were expected to be unknown to the designers, designers were able to indicate if they already knew the information. This ensured that if the information was already known we could exclude it from our analysis.

Finally, the dimension of "appropriateness of form" was omitted for two reasons. First appropriateness of form was expected to be an issue implicated in the perceived cost of obtaining the information. Secondly, since we were using questions about information and not the actual information itself, the appropriateness of the form of the information could not be evaluated.

(3) Recalling that Rouse distinguished between information that was relevant and necessary and information that was relevant and discretionary, we added a necessary–discretionary dimension. Information now covered four quadrants: relevant and necessary, relevant and discretionary, not relevant but necessary, and not relevant and discretionary. Rouse's categories were preserved with the additional possibility that research information might be both not relevant and discretionary. This necessary–discretionary dimension was captured in the single variable of *importance*, defined in the sense that important information is indispensable in solving a design problem. We had the respondents rate the Importance of the information, in terms of how necessary it would be in solving a design problem, along a semantic differential scale.

(4) To evaluate Rouse's claim that almost all research information falls in the category of

discretionary, we needed to look at the responses along the Importance scale. Since our interest was the evaluation of human factors research information, our conclusions are limited to this area and in fact, to only those pieces of information which were targeted by the questions we sampled. We did, however, randomly select questions from those available in the EDC and further, we excluded sections of the book which would obviously be of little importance to designers of control rooms.

The areas of the Design Checklist selected were:

(1) Monitoring and Supervisory Control
(2) Workload
(3) Human Reliability and Error Prediction
(4) Auditory Alarms
(5) Visual Search
(6) Visual Information Representation and Coding
(7) Hand-Activated Controls.

Each of these subject areas is directly relevant to the ergonomic design of control rooms. Within each of these areas, five questions were randomly selected. The questionnaire consisted of a total of 35 design questions sampled from the EDC. The questions were presented in random order. The section headings from the EDC listed above were also provided to subjects, as some of the questions could be difficult to understand without the heading. Table 1 contains an example of one of the questions.

(5) Rouse's claim that information would only be accessed if its perceived value was greater than its perceived cost was formally developed into the following model:

$$\text{Accessing Behavior} = f\,(\text{Perceived Value, Perceived Cost}),\ \text{where Accessing Behaviour} \geqslant 0. \tag{1}$$

To include Rouse's ideas on the value of information we let

$$\text{Perceived Value} = f\,(\text{Importance, Relevance}). \tag{2}$$

Because of the nature of this study, it was not possible to get a true measure of the Accessing Behavior of these designers. Forcing the designers to search for the information or to perform a laboratory-style project would have destroyed the naturalistic setting which we needed for our results. To deal with this problem, we had the designers give ratings of the Effort which they would be willing to spend to obtain the information along a scale from 0 to 100. This was meant to be consistent with Rouse's idea that value is what one would be willing to spend for the information in terms of money or effort. To ground the effort scores in terms of realistic information search activities, we also had the respondents give effort ratings for using a number of different information sources. The resulting model can be described as follows:

$$\text{Accessing Behavior, reflected by Effort} = f\,(\text{Perceived Value, Perceived Cost}),$$
$$\text{where Perceived Value} = f\,(\text{Importance, Relevance}) \tag{3}$$

Or, in total

$$\text{Accessing Behavior, reflected by Effort} = f\,(\text{Importance, Relevance, Cost}). \tag{4}$$

METHOD

A questionnaire study was conducted to evaluate the model of information search criteria just described. If Rouse is correct, then one would expect that the decision to access design information would be based on designers' perceptions of the Importance, Relevance, and Cost of that information. Furthermore, Subject and Question should *not* be good predictors.

Subjects

The questionnaire was distributed to human factors designers in the nuclear industry. The study was limited to a single industry in order not to confound effects from different industrial contexts. This approach also allowed us to meaningfully integrate the results of this investigation with those of another study of design that we conducted in the nuclear domain (see Burns, 1994). Of forty questionnaires distributed, twenty responses were received, 18 of which were scoreable.

Design of the questionnaire

The questionnaire consisted of two sections, the first containing background questions, and the second containing a set of hypothetical design questions that respondents were asked to rate along several dimensions.

Background section. The first few questions addressed the subjects' background, their experience in design and in human factors, as well as their job responsibilities. Two additional questions addressed subjects' opinions about design constraints and criteria governing information search.

The most important part of this section was devoted to eliciting subjects' ratings of the time and effort associated with different sources of design information. As shown in Table 2, a list of sources of design information was constructed. The scale was anchored on the low end by assigning an effort rating of 0 to the source, "already know the answer". For the remainder of the information search activities, subjects were asked to assign a cost/effort score representing the amount of time and effort they thought was associated with using that information source. This procedure allowed us to develop an effort/cost scale tailored to each subject's perceptions.

The responses on this scale were critical for relating the Effort and Cost ratings to real information search activities.

Question rating section. The second section of the questionnaire asked subjects to rate the design questions along several dimensions. These dimensions were the four dimensions of the model developed in the previous section: Cost, Effort, Importance and Relevance.

(1) *Cost* in terms of time and effort to find the answer to the question. Since the respondents were not aware of the source of the questions, they could perceive some answers to require more or less effort than that associated with looking in a handbook. The respondents were encouraged to recall their answers to the first section of the questionnaire, where they developed their cost/effort scale shown in Table 2, as a guide to assigning a cost score.

(2) *Importance* of the answer to the question in an actual design project. Important information is that which is necessary for a project to be completed. This was to explore the discretionary–non-discretionary dimension suggested by Rouse (1986).

Table 2. Development of a personalized cost/effort scale

The following is a list of ways of obtaining information. Assign a cost score to each method. For cost, consider the amount of time and effort you think it would take. As a guideline, consider the following scale. The items are in no particular order. Equal cost items may be given the same score.

0	20	40	60	80	100
No cost					High cost

___ consult operators or users
___ conduct a formal experiment
___ conduct an informal experiment
___ already know the answer
___ use personal judgement
___ ask a local colleague
___ phone or email a colleague
___ consult a journal article you have
___ look for a journal article in a library
___ look up a previous or similar design
___ access a computer-based database
___ look up in a handbook or textbook
___ use an analytical model

(3) *Relevance* of the information is a measure of how often a given human factors issue occurs during design. This was to explore the relevance factor suggested by Rouse (1986).

(4) *Effort* subjects were willing to expend to find the answer to the question. When rating this dimension, the respondents were again encouraged to consult the cost/effort scale they developed in Table 2.

The four rating scales were end-anchored semantic differential scales with 5 segments along the scale. Subjects could skip the ratings for any question by checking a box indicating that they did not understand the question. Table 1 contains an example of one of the survey questions. Following the evaluation of all of the questions, the respondents were provided with an open-ended question asking for their comments. The entire questionnaire was pre-tested on a group of pilot subjects to identify and remedy any potential problems (Burns, 1994).

RESULTS

The results of the evaluation are presented in this section. There were 20 responses, 18 of which were scoreable. First, we examined whether the questionnaire was successful at eliciting perceptions of information, that is without revealing the information itself. Next, the results of the scores on the discretionary dimension are examined to see whether or not this research information was considered discretionary by these designers. Finally, the success of the model developed from Rouse's ideas [equation (4)] is discussed.

(1) Perceptions of information by the recipients

In terms of recipients, the questionnaire was targeted at human factors designers in the nuclear industry. The important criteria were that the respondents were involved in design and in human factors design in particular. The background of the sample group was mostly engineering with 13 out of 18 respondents from an engineering background, 4 out of 18 from psychology, and 2 from other disciplines. (One subject listed both engineering and psychology backgrounds.) All subjects had experience with human factors, ranging from 3 to 35 years with an average experience of 9.58 years (SD=8.35). Experience with design was similar with an average experience of 10.67 years (SD=8.22). Eleven of the respondents said they were currently doing design work and 100% of respondents listed that they were currently doing one or more of design, evaluation of design, or development. Given these results, the sample group seemed to correspond well with the desired population.

Only one of the 20 respondents indicated that he knew the answers to some of the questions. We counted this questionnaire as unscoreable. The other respondents were not aware of the answers to the questions or of the source of the answers to the questions. It seemed that the questionnaire was successful in eliciting perceptions of information without revealing the information itself. Verbal reports from some of the non-respondents indicated that they perceived the questions being asked to be of such low importance and relevance that they did not feel it was worthwhile to continue completing the questionnaire. This suggests that the trends found, and discussed in the next section, may be conservative.

(2) The importance of this research information to these designers

For this, we looked at the scores on the Importance scale. The average scores by question are shown in Fig. 1, which indicates a majority of ratings of (26/35) in the lower half of the range, suggesting that the respondents in general consider most of the questions asked to be of low importance and not necessary to solving a design problem.

(3) Results of the model

Models of the form Effort=*f*(Importance, Relevance, Cost) were explored. The results of the modeling were examined in both an aggregate form and in terms of individual models.

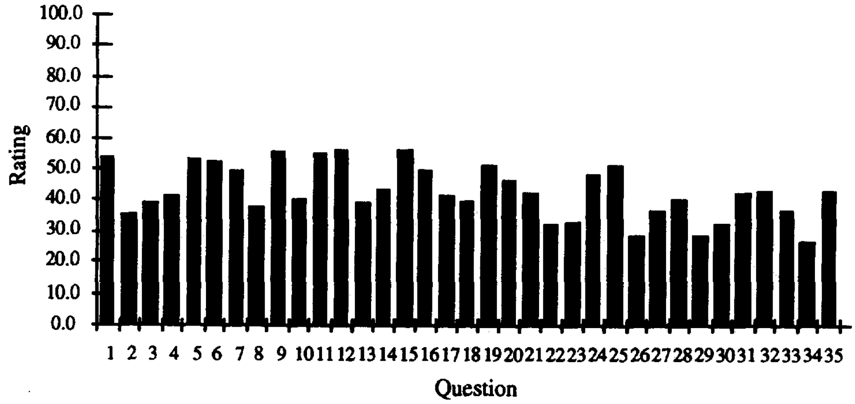

Fig. 1. Ratings of importance for all questions.

Aggregate model. Following the recommendations of Walker and Catrambone (1993), the data of all subjects on each of the four scales were pooled. Furthermore, Subject Number and Question Number were retained as variables to determine whether they were unexpectedly accounting for a significant amount of the variance. Correlations were run between all variables and then various linear regression models were explored. Correlations between all variables are presented in Table 3.

In this case, $N=577$ and the 53 cases with missing values represent questions that subjects did not understand and therefore skipped. Skipped questions seemed to fall into two groups: questions which were only skipped once or twice, and questions which were skipped by 3 to 6 respondents. For a more thorough analysis of these questions, see Burns (1994).

The highest correlations were found between Effort and Importance, Effort and Relevance, and Importance and Relevance. This suggests that the Effort the respondents were willing to expend was a function of the perceived Importance and Relevance of the information and that, possibly, Importance and Relevance were indistinguishable.

To test the model, a stepwise linear regression analysis of the data was conducted to determine which variables best predicted the subjects' ratings of Effort. All potential variables (Value, Cost, Subject Number, and Question Number) were included in the analysis. With regard to Value, both additive (I+R) and multiplicative (I*R) relationships were investigated. The stepwise regression thresholds were generously set at $F=5$ to enter and $F=4$ to exit in order to allow all possible variables to enter the model.

The I+R model accounted for 59% of the variance, of which 56% is accounted for by the first variable, Importance ($F_{remove}=164.5$). Relevance was the second variable entered ($F_{remove}=25.029$). Cost and Subject Number did appear as late entering variables but mostly a result of the low F-threshold settings ($F_{remove}=11.039$, $F_{remove}=13.276$, respectively) and they did not significantly increase the % variance explained.

The I*R model accounted for almost 61% of the variance, 58.6% of which was explained by the first variable I*R ($F_{remove}=685$). Thus, the multiplicative model provided a better model, but

Table 3. Correlations between all variables, $N=577$

	Subject No.	Question	Cost	Effort	Importance	Relevance
Subject No.	1					
Question No.	0.032	1				
Cost	− 0.069	− 0.037	1			
Effort	0.047	− 0.105	0.365	1		
Importance	0.177	− 0.184	0.356	0.748	1	
Relevance	0.259	− 0.179	0.286	0.658	0.781	1

Table 4. Results from individual regression models

Subject	I	C	R	Question No.	r^2	Intercept	r^2 (I*R)	R1 − R2	Model	Model 2
1	0.482	0.152	0.152	•	0.886	− 10.445	0.924	− 0.038	E=I,R,C	E=V,C
2	0.676	•	•	•	0.83	8.376	0.652	0.178	E=I	E=V
3	•	•	0.902	•	0.832	3.201	0.847	− 0.015	E=R	E=V
4	•	•	0.414	•	0.462	13.533	0.429	0.033	E=R	E=V
5	•	•	1.098	•	0.881	− 15.027	0.887	− 0.006	E=R	E=V
6	0.379	0.697	•	•	0.896	− 2.738	0.898	− 0.002	E=I,C	E=V,C
7	•	•	0.955	•	0.926	1.495	0.888	0.038	E=R	E=V
8	0.696	•	•	•	0.413	3.248	0.439	− 0.026	E=I	E=V
9	0.335	0.375	•	•	0.667	3.258	0.641	0.026	E=I,C	E=V,C
10	0.542	•	0.461	•	0.756	− 20.438	0.785	− 0.029	E=I,R	E=V
11	•	1.521	•	•	0.663	− 3.3	0.663	0	E=C	E=C
12	0.285	•	•	•	0.268	9.259	• model failed	•	E=I	E=V
13	0.465	•	•	•	0.581	15.967	0.299	0.282	E=I	E=V
14	•	•	0.624	•	0.433	4.13	0.467	− 0.034	E=R	E=V
15	0.31	− 0.48	0.361	•	0.515	31.732	0.543	− 0.028	E=I,R,C	E=V,C
16	0.451	0.367	•	0.34	0.88	− 18.985	0.763	0.117	E=I,C,Q	E=V,C,Q
17	0.781	•	0.305	•	0.861	− 8.331	0.852	0.009	E=I,R	E=V
18	•	0.496	•	•	0.248	22.815	0.248	0	E=C	E=C

not substantially so.

Individual models. It was not unreasonable to suspect that respondents may have differed in the factors that they considered when determining how much effort they would expend to obtain design information. Therefore, we evaluated the models exhibited by individual subjects. Again, both additive and multiplicative forms were evaluated. These models were run using a stepwise algorithm to include variables of a strength $F \geqslant 5$.

Table 4 contains the results for each subject. The four variables of Importance, Cost, Relevance and Question number are in columns 2 to 5, respectively. If the variable was included in the regression model, is coefficient is shown, otherwise the table cell is left blank. To conserve space in this table, the variables are indicated by their first letter. "V" represents the Value of information, where Value=f(Importance, Relevance). Column 6 contains the r^2 value for each linear additive regression model of the form y=f(I,C,R,Q,). Column 7 holds the intercept from the regression. In column 8, the r^2 value from the multiplicative I*R model of the form y=f(I*R,C,Q) is shown. In column 9, the difference in r^2 values between the additive and the multiplicative models is provided. In all cases, it can be seen that the multiplicative model, I*R, was not substantially better at fitting the data. Consequently, the coefficients from this algorithm are not displayed. Columns 10 and 11 categorize the type of model found. These models are discussed in more detail later.

Several findings can be extracted from this table:

(1) There is variability in the individual models that best fit the ratings of each subject. The seven models identified are:
   (a) Effort=b_0+b_1Importance+b_2Relevance+b_3Cost [E=I,R,C]
   (b) Effort=b_0+b_1Importance+b_2Relevance [E=I,R]
   (c) Effort=b_0+b_1Importance+b_2Cost+b_3Question Number [E=I,C,Q]
   (d) Effort=b_0+b_1Importance+b_2Cost [E=I,C]
   (e) Effort=b_0+b_1Importance [E=I]
   (f) Effort=b_0+b_1Relevance [E=R].
   (g) Effort=b_0+b_1Cost [E=C].

(2) For some subjects, 7 out of 18, Cost was one of the factors under consideration. In all cases but one, the Cost coefficient was positive, suggesting that the higher the perceived cost of the information, the more effort respondents were willing to expend to obtain that information.

(3) The perceived value of the information (as measured by Importance and Relevance)

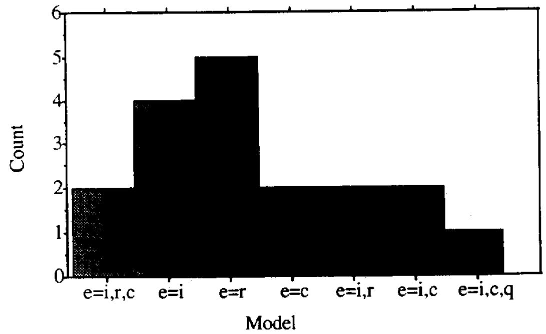

Fig. 2. Frequency of individual models.

was always a significant factor. Importance, Relevance, or both were factors in the models of all but two subjects. These coefficients were always positive.

(4) These models fit different subjects' responses with varying degrees of success. For 8 subjects, excellent fits were found (r^2>0.8). For 2 subjects, the models were poor (r^2<0.4). Further analyses of demographic variables did not reveal why these two subjects demonstrated such poor fits (Burns, 1994).

(5) The multiplicative model was never substantially more successful than the more parsimonious additive model. The greatest improvement in the variance accounted for is only 3.4%.

(6) One subject showed a positive coefficient for question number. This subject's responses may be drifting higher as they proceed through the questionnaire.

Figure 2 shows the frequency of the different model types, the E=I and E=R models were the most common. For the most part, however, Importance and Relevance were highly correlated variables. This can be seen from the fact that most models include Importance or Relevance but not both, one adding little new information to the other. It was not unreasonable, therefore, to develop a composite model where Importance and Relevance were considered to be measures of the same of quantity, some measure of the Value of the information.

Following this, we considered those models where E=I, E=R, and E=I, R to be essentially the same model. This simple model was clearly the most common, providing the best fit for 11 out of the 18 respondents. However, this result is not significant (binomial test, P>0.10).

Relation to real information search activities. The intended effort ratings obtained by the questionnaire may differ from real information search activities. Smithson (1994) has noted large discrepancies between information retrieval intentions and actual retrieval behavior. To give some grounding to the ratings, though, the subjects also gave effort ratings for using the different information sources listed in Table 2. The rating of these soruces are shown in Fig. 3. In comparison with other sources of information, human factors handbooks were considered to be relatively low effort resources at an average value of 25.8.

We compared the Effort ratings with the effort to use a Handbook rating. Figure 4 shows the intended Effort minus the Effort for using a Handbook. Any positive value suggests that the respondents were willing to spend at least as much effort as using a handbook would require. In most cases, 26/35, the respondents were willing to expend effort levels greater than those levels required to use a handbook. This result seemed encouraging as it suggested that the respondents were willing to expend the effort required to obtain this information.

We explored further though and compared the ratings of Cost to obtain the information with the handbook effort score. Recall that both these ratings were made by the respondents using their individual cost and effort scale from Table 2 as a guide. A consistent tendency, 34/35, to overrate the difficulty of obtaining the information was seen (P<0.00006 binomial test for single samples, normal approximation with a continuity correction two-tailed). Figure 5 shows the average differences by which the subjects' cost scores exceeded their own handbook score

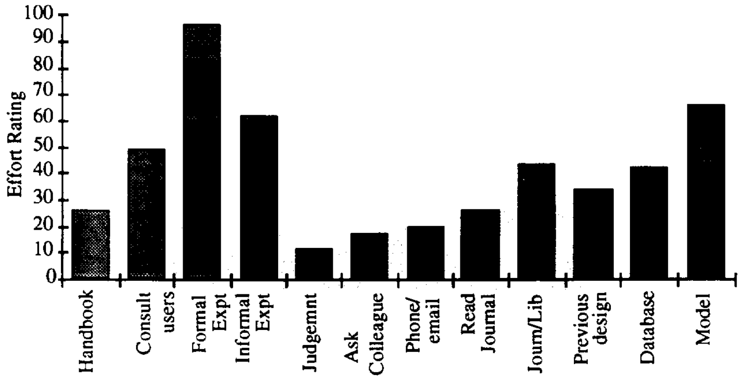

Fig. 3. Effort ratings of different information sources.

for each question. A positive value indicates an overrating of the cost to obtain the information. That is, designers thought it would cost more to find the information than it actually does. The total incidence of this behavior was 406/577 possible occurrences. (N of 577 reflects the total number of questions answered not including the 53 skipped questions.)

This was a disturbing trend—if designers perceived human factors information as being

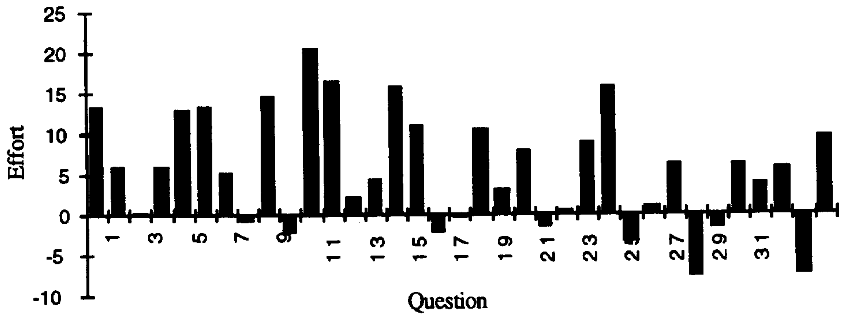

Fig. 4. Effort – handbook effort.

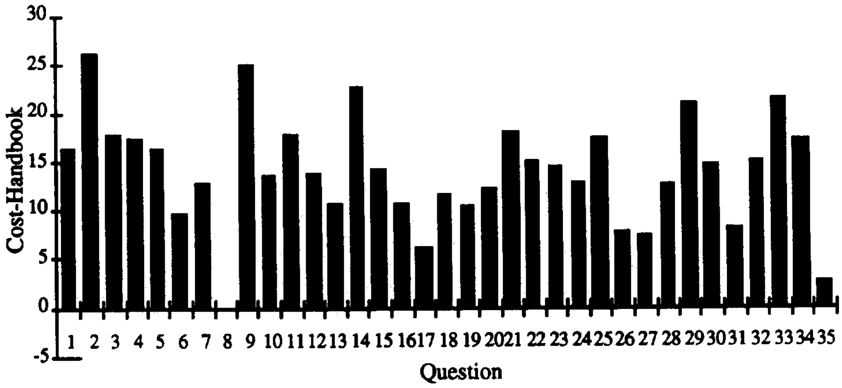

Fig. 5. Cost – handbook effort.

costly to obtain, it does not seem likely that very much human factors information will be searched for.

CONCLUSIONS

This study investigated the criteria that designers use to make judgments at the earliest stages of design information acquisition, when they decide whether to access information. A model, based on the work of Rouse (1986), suggested that judgements about information search would be based on the perceived relevance, importance, and cost of the information being sought. Rouse also suggested that we would find that designers often considered research literature to be discretionary. Although these ideas may be intuitively appealing, they had not been empirically evaluated before in a form that closely followed Rouse's original ideas. A questionnaire study was conducted to explore these ideas with a group of designers from the nuclear industry.

How well did the model account for subjects' ratings? As predicted, Subject and Question were very weak predictors of the value of information. Furthermore, we found that a subjective rating of intended search effort was predictable from the perception of the value of the information. In some cases, but not all, the perception of the cost to obtain was also a factor. Importance, the discretionary dimension, was always highly correlated with relevance. This suggests that designers do not differentiate between relevant and necessary information and relevant and unnecessary information. What is relevant and what is necessary are one and the same thing.

Designers made judgements of the expected costs to obtain the information. In only a few cases though did these judgements affect their estimation of the effort they would spend to obtain the information. A disturbing trend though, was that designers consistently overrated the cost to obtain the information.

Rouse's suggestion that research information is discretionary to design seemed to be supported. In all cases, the judgements on the discretionary scale were seen to be quite low. These results, however, are limited to this set of human factors reference information and this particular group of human factors designers.

The fact that these ratings were so low should be considered when interpreting the findings from the modeling. It is possible that these modeling results only reflect the relationships between the variables for discretionary information and that different results might be obtained when designers were rating highly important information. Another consideration is that the model found, Effort=*f*(Value), suggests that, were value unlimited, designer effort would also be unlimited. This is surely incorrect since the resource-limited nature of the design process would certainly cause a limiting effect on designer effort. The Effort=*f*(Value, Cost) model predicted by Rouse would seem more realistic in this regard. The absence of perceived cost as a predictor for most subjects may simply be due to the fact that the design questions they were rating were of low value. Thus, cost would logically not have been a limiting concern. Given this interpretation, it seems that the findings are generally consistent with the Rouse model.

When considering the costs of obtaining information, it seems that the context in which the costs are incurred is important. It may be that the cost itself is not really the critical aspect, but rather, that it is the pragmatic effect that the cost has on the course of a design which is important. As an example, 10 minutes to look up a piece of information on a slow day may have no effect, but when the designer has 15 minutes left to prepare for a crucial design meeting, the effect may be tremendous. A better way of looking at this cost may be to examine the value of the cost, in a negative sense, to completing a design project. This might suggest a new model exploring the effort designers are willing to expend as a function of how they perceive the information will move them towards design goals, *positive value*, and away from other goals, *negative value* (cf. Burns, 1994). If this view is correct, then perceived cost cannot be measured as it was in this study. Instead, it could only be meaningfully assessed within the setting of a specific design context. This constrast between these two perspectives is worthy of investigation.

One of the limitations of this study is that the ratings obtained cannot be used to directly predict information search activities. It is unclear whether a statement of intended effort is a reliable predictor of actual search effort. Smithson (1994) found that intention to search and actual information retrieval can be quite different, finding that searchers retrieved only a fraction of items that they stated they intended to retrieve. If anything, our results may paint an overly optimistic picture of designer's expected use of information. The actual problem may be even more serious.

These conclusions must be tempered by the fact that only one industry and one set of information were sampled in this study. We simply do not know to what extent these findings can be expected to generalize outside of the nuclear industry or to other sets of research information. It is understood that designers in different domains and working on different projects will judge the relevance of information differently—these questions, however, were randomly sampled from the most relevant sections of a comprehensive source, yet the value judgements obtained were consistently low. There does not seem to be any strong reason for suspecting that the information search criteria of other designers will be vastly different.

Implications. The models found in this study suggest two ways of increasing the effort that designers will spend to obtain information. The first would be to reduce the cost of obtaining the information. This could perhaps be accomplished by providing designers with tools or design associates (Cody *et al.*, 1993), which integrate information resources directly with other design tools. A second possibility is to provide on-line references which provide for quick search and access (e.g. Monk *et al.*, 1992). However, this latter approach would only succeed if the reference information was relevant to design in the first place. A third way to potentially reduce the cost of obtaining information would be to create reference information that is closely matched with the context and form of actual design problems (cf. Vicente *et al.*, 1993). In this way, designers would not need to extrapolate results from other domains, or worry about whether or not information obtained under experimental conditions will be applicable in complex real-world situations. This would be a potentially more effective but much more daunting alternative. Another concern that arises out of this study is that even though designers do not consider reference books to be exceedingly high cost sources of information, they seem to be unfamiliar with what information is readily available and consistently overrate the costs of obtaining information. More education, or knowledge bases that invite designers to explore them might help to correct this misperception.

Given what we have learned from this study and from our other studies of design and designers (Burns & Vicente, 1994), it would seem that the greatest gains are to be had by increasing the value judgements made by designers. Given the high experience level of these respondents, these results strongly suggest that this human factors information is not important to these designers. This means that human factors as a discipline must make a strong and unified commitment to:

(a) provide information that is of high value to design,
(b) make the design implications of research results clear, and
(c) emphasize design improvements which have resulted from the use of human factors information.

As for areas for future research, two paths stand out. The first would be to firmly establish how perceptions of value and cost translate directly into actual information search activities. The second would be to look at the subsequent stage of information utilization to examine what conditions determine whether or not information that has already been accessed will be used to impact a design.

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