Human Factors and Global Problems: A Systems Approach

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Received June 1, 1997; accepted February 15, 1998

ABSTRACT

The potential catastrophic impact of global problems on contemporary society has received a great deal of public attention in recent years. Many of these problems can only be solved, not just by technological innovation, but also by changing human behavior (e.g., having less children, producing less waste, consuming less electricity and water). This paper describes how the discipline of human factors (or ergonomics) can play a unique role in helping to solve such global problems. Two illustrative design principles—behavior-shaping constraints and salient, immediate feedback—are discussed. In addition, examples of how these principles can potentially be applied to the following problems are provided: conserving energy expended by desktop computers; reducing photocopier paper wastage; conserving residential utility consumption; and reducing water wastage from faucets. If more products were designed in this fashion, then the aggregate contributions could amount to a worthwhile improvement in global problems. © 1998 John Wiley & Sons, Inc. Syst Eng 1: 57–69, 1998

1. INTRODUCTION

Though we cannot live one hundred years, we should be concerned about one thousand years hence.

—from a famous classic Chinese poem

Traditionally, the discipline known as *human factors* (or ergonomics) has been concerned with the design of devices, environments, and workplaces that take into account human capabilities and limitations. Human factors has been applied to a wide variety of problems, from the design of control rooms for nuclear power plants [e.g., Vicente, 1992] to the design of the Reach toothbrush [Guilfoyle, 1977]. Based on the knowledge generated by the discipline, many textbooks [e.g., Sanders and McCormick, 1993; Kantowitz and Sorkin, 1983; Wickens, 1992] and handbooks [e.g., Salvendy, 1987; Van Cott and Kincade, 1972] have been written over the years. However, if we examine the contents of these books, we will find very little that is directly relevant to the solution of global problems. Human factors has not been concerned with such problems, despite the fact that many global problems have an obvious human component to them [Nickerson and Moray, 1995].

Thanks to the seminal work of Nickerson [1992], and more recently Moray [1993, 1994], this situation is beginning to change. This paper describes how the human factors principles being developed by these researchers can be adopted to make a unique and significant contribution to the solution of some of our most pressing global problems. A key idea which is beginning to emerge in this area is the notion of *behavior-shaping constraints*, which has its foundations in cognitive systems engineering [Rasmussen, Pejtersen, and Goodstein, 1994]. This systems approach can lead to novel methods and ideas for addressing global problems from a human factors perspective.

The remainder of the paper is organized as follows. First, a justification for why human factors can contribute to global problems will be provided. This is an important point to make since only a very few people have made the connection between this discipline and these pressing challenges. Second, some of the key principles that have been derived from a systems approach to human factors will be described. These principles provide a source of insight that can be used to address a very wide variety of problems. Third, several hypothetical examples showing how these principles can potentially be applied to global problems will be provided.

Much of the inspiration and conceptual content of this paper is derived from the work of Nickerson [1992], and especially Moray [1993, 1994]. The interested reader is referred to these works for a more detailed treatment of this topic. Also, see Norman [1988] for an easy to read treatment containing numerous examples based on similar design principles, but in the context of more traditional application areas.

2. WHY CAN HUMAN FACTORS HELP SOLVE GLOBAL PROBLEMS?

The fact that human factors as a discipline has a unique role to play in addressing global problems has not occurred to most people, not even most human factors researchers and practitioners. Thus, it is important to explain this relationship clearly.

Moray [1994: 4] has arguably been the one to make this point in the most direct and vigorous fashion in his keynote address to the International Ergonomics Association meeting: "the solutions to the problems of the 21st Century absolutely require the redesign of society to change human behavior." Examples of such desired behavior changes include: having less children, producing less waste, consuming less electricity and water, being more understanding of other cultures, recycling more frequently and efficiently, maintaining and making full use of the available arable land on earth, ceasing from polluting the environment, and designing safer technological systems that do not lead to ecological disasters. All of these problems have a human component to them.

Moray goes on to explain that traditional human factors can actually be viewed as the engineering discipline concerned with changing human behavior. Although this is an unorthodox description of human factors, it is a productive one to adopt since it makes the connection to global problems more obvious. Take a typical design problem that human factors engineers have been concerned with, such as designing a remote control for a programmable VCR. There is an obvious technological dimension to this problem, but the role of the human factors engineer is to design a remote control that will be useful as well as easy to learn and use, thereby reducing the probability of errors. This is accomplished by manipulating certain features of the device (e.g., the size, position, and organization of the buttons; the wording of the labels; the logic of the programming sequence; the feedback provided by the VCR). By arranging these design features in a manner that is consistent with well-established human factors principles, the engineer can *induce* desired functional behaviors, namely, efficient and reliable use of the device. On the other hand, by arranging these design features in a way that violates existing knowledge about human capabilities and limitations, the engineer can induce (probably unwittingly) dysfunctional behaviors, namely, inefficient and error prone operation of the device (see Norman [1988] for many examples). This hypothetical example should make it clear that human factors is "in the business" of designing workplaces and devices to induce functional changes in human behavior.

From this perspective then, applying human factors to global problems is not such a foreign concept. The goal is still to change human behavior; the only thing that is really different is the nature of the problems, and, thus, the type of behaviors that need to be induced. Rather than shaping interaction with a VCR remote control, human factors engineers can, and should, be concerned with shaping the interaction between humans and other humans and between humans and their environment. This is not to say that human factors can lay a privileged claim to solving these challenging problems. Global problems cannot be solved by a single discipline. The important point, however, is that the discipline of human factors has a unique contribution to make since it is especially qualified to deal with the human dimension of these problems.

What can happen if human factors is ignored? The answer is simple. If the desired behavior changes are effortful to make, people generally will not perform them. A simple case is that of recycling. Early efforts at recycling failed because they demanded more effort on the part of the people then they were generally willing to expend. Thus, the desired change in behavior was not achieved in the vast majority of the population. As Moray [1994: 10] observes, “people are not very good, over the long term, in undertaking difficult, inconvenient and demanding patterns of behavior on a voluntary basis.” To create the conditions that are required to make desired behaviors natural and easy for people requires a great deal of knowledge about human capabilities and limitations. The next section will describe some of the principles that have been developed in human factors to achieve this important goal.

3. A SYSTEMS APPROACH: DESIGN PRINCIPLES

How can functional behaviors be induced in people so that progress can be made on global problems? There are several obvious candidates, such as public information, education, and legal legislation. While all of these have their place, they all suffer from various disadvantages. Public information campaigns are frequently not heeded. Education is a very slow process and is probably only likely to succeed with younger generations who have not yet settled on dysfunctional patterns of behavior. Laws are difficult to pass because of special interest lobby groups, and even when they are passed, they may not be completely effective if they demand effortful behavior (e.g., seat belt laws in the 1970s when the designs were more cumbersome to use). Thus, it is important to search for alternative ways of changing people’s behavior over the long term.

This section describes two important human factors design guidelines that can be used to elicit desired behaviors: behavior shaping constraints, and immediate, salient feedback.

3.1. Behavior Shaping Constraints

As mentioned earlier, a key idea that is beginning to emerge in applying human factors to global problems is that of behavior shaping constraints. This idea has its origin in systems theory [e.g., Rasmussen et al., 1994]. However, it also has ties to the concept of *affordance*, which was originally developed within the school of psychology known as ecological psychology [Gibson, 1979], but which is also recently beginning to exert an influence on the human factors community [Flach, Hancock, Caird, and Vicente, 1995; Hancock, Flach, Caird, and Vicente, 1995]. An affordance is a possibility for action offered by an object, whether that action is functional or dysfunctional. For example, a chair affords sitting to an adult human, but perhaps not to a toddler. The concept of affordance is important because it is a way of discussing the properties of an object in terms that are relevant to human action. This derives from the fact that affordances are defined with respect to the action capabilities of a given actor. As the preceding example makes clear, a given object can have an affordance for one actor but not for another. Moreover, one object can, and usually does, have multiple affordances. For instance, a chair not only affords sitting to an adult but it can also afford throwing (if it is light enough) or burning (if it is made of wood and the actor has a match).

It is possible to restate the objective defined earlier in terms of the concept of affordances: The goal of human factors should be to design objects that have easy to perceive and easy to use functional affordances, but that do not have any dysfunctional affordances. The design of affordances is equivalent to the design of behavior-shaping constraints. We should be designing systems that will elicit the desired behaviors that will help ameliorate global problems, whether or not people voluntarily undertake those behaviors [Moray, 1994].

This may seem like a magical concept, but a few simple examples should suffice to illustrate its value and feasibility. At least one automobile manufacturer has designed its keys in such a way that it is essentially impossible to insert the key into the lock in the wrong direction by virtue of the fact that the key is symmetrical; as long as the key is aligned with the lock, it will go into the lock, regardless of whether it is “upright” or “upside down.” In fact, these adjectives, which can be used to describe many keys that are not designed this way, are not meaningful for this design—there is no such thing as upside down. Thus, the key–lock system has an easy to perceive and easy to use, functional affordance. Or alternatively, the system is designed to make it easy to do the right thing and very difficult to do the wrong thing. This is the fundamental idea behind the concept of behavior shaping constraints.

Another example can be used to illustrate the wide applicability of this design concept. Many computer notebooks have removable rechargeable batteries that are rectangular in shape. Because the shape of the battery is symmetrical about several axes, there may be several ways to insert it back into the computer. In contrast with the key example, symmetry is an undesirable feature in this case because there is only one orientation that will allow the battery to function properly once it is inserted into the computer. Thus, it may be easy to insert the battery in the wrong way. At least one computer manufacturer has addressed this problem by constructing the battery shape in such a way that it has several notches in it that deviate from what would otherwise be a symmetrical form. As a result of this design, the battery will only physically fit back in the computer in one orientation. As with the previous example, it is very difficult to do the wrong thing and very easy to do the right thing. Norman [1988] provides other examples illustrating this basic idea.

The two examples just described shape behavior by physically constraining human behavior. However, it is possible to induce functional actions in another way, namely, by making it easy to "do the right thing," despite the fact that dysfunctional actions are equally easy. A very good example of this type of behavior-shaping constraint is cited by Moray [1994]. Apparently, in Australia some toilets are designed in such a way that they can be operated in two modes. In one mode, only half a tank of water is flushed, whereas, in the other mode, a full tank of water is flushed. Each mode has a different handle associated with it, each with an appropriate iconic label. The handle with an icon that is only half-shaded operates the more economic mode, while the handle with the fully shaded icon operates the less economic mode. In this design, the user always has the choice of which handle to depress for any given usage. However, the design is structured in such a way as to encourage users to utilize the more economic mode after urinating and the "full tank" mode after defecating. The design is wonderfully simple, yet very compelling. It makes it very easy to "do the right thing," thereby representing a prototypical example of behavior-shaping constraints that do no violate free will.

The following section will provide several examples illustrating how the idea of behavior-shaping constraints can be applied to ameliorate a global problem. First, however, another human factors design principle, which can be considered a special case of behavior-shaping constraint, will be described.

3.2. Salient, Immediate, Feedback

Another important design principle that can help in designing systems that result in functional changes in behavior is that of feedback. Although the concept of feedback also has its origins in systems theory (control theory, in particular), it is also very relevant to psychology and human factors as well. Providing people with salient, immediate feedback regarding the functional value of their actions is a very efficient and effective way of changing people's behaviors. Unfortunately, this design principle cannot be applied in some situations, since the consequences of an action are not known until a great deal of time has elapsed. However, there are many situations where this principle can be used to great effect.

Fire is a simple yet powerful example of the value of providing immediate, salient feedback in changing behavior. We do not have to get burned in order to determine that a campfire, for instance, can have detrimental effects. As we approach the fire, we can feel the heat increasing commensurately. Backing up provides a source of welcome relief, whereas even a step forward can provide a very immediate, salient warning not to go any further. Contrast this situation with the feedback provided by radioactivity. In the latter case, there is no natural source of information that one can use to detect that danger is imminent: radioactivity cannot be seen, felt, heard, smelled, or tasted. In essence, it poses an invisible hazard. But what if radioactivity provided the same type of feedback as fire? Clearly, this would result in a marked change in behavior. If these examples have not convinced the reader of the behavioral value of providing immediate, salient feedback, consider the impact on the AIDS epidemic if the feedback available as to the consequences of one's actions were the same as that naturally associated with fire.

3.3. Summary

This section has discussed two simple, but potentially very powerful, design principles based on a systems approach to human factors. Although there are limits to the practical applicability of each principle (especially, feedback), they can both be applied in a wide variety of situations to modify people's behaviors. More importantly, they can potentially be applied to effectively address the human aspect of many global problems, as the next section will try to show.

4. APPLICATION EXAMPLES

This section will describe a number of examples showing how the concepts of behavior-shaping constraints and feedback can be applied to ameliorate global problems. Needless to say, none of these examples completely solves any one global problem. The examples are much more modest in scale addressing a particular, narrow activity involving human behavior which affects a global problem. In addition, the examples are not meant to be definitive design concepts. For example, issues associated with economic and technical feasibility have not been addressed in detail. Also, none of the examples has been empirically proven to lead to the intended changes in behavior. Therefore, the examples are merely presented as innovative, plausible, and hopefully convincing applications of the design principles described above to situations in which human behavior is currently contributing to a global problem in some substantial way.

The problems addressed by the examples are as follows:

- conserving energy expended by desktop computers
- reducing photocopier paper wastage
- conserving residential utility consumption
- reducing water wastage from faucets

Each of these examples will now be discussed in turn.

4.1. Conserving Energy Expended by Desktop Computers

As computers are introduced into more and more workplaces at an ever increasing pace, the amount of energy consumed by those computers increases accordingly. Although this is by no means the most critical piece to the global energy conservation puzzle, any contribution towards ameliorating this local problem can only help with the global problem as well.

Kuk, Cowley, and Beserve [1994] adopted the human factors systems approach described above in developing a potential solution to this problem. They began their efforts by conducting an analysis to understand the nature of the underlying problem. The first step was to establish the magnitude of the issue. One might think that the amount of energy consumed by computers is negligible. However, according to the U. S. Environmental Protection Agency, "5% of the power used by American companies is consumed by computers, and ... without regulation this figure could reach 10% by the year 2000" [Fox, 1994: 22]. These figures could be interpreted as an indication of the inevitable cost of doing business in the computer age. Upon closer examination, however, we find that the costs are not as inevitable as one might think, since 40% of computers are left on overnight, using up valuable energy [Fox, 1994]. Of this valuable energy, approximately 60% is used by the monitor alone. Thus, we see that this problem, like many others, has a significant human component to it. If only we could elicit a change in behavior (i.e., inducing people to turn off their computers when they are not being used), then a substantial impact could be made, not only financially, but also ecologically as well. Before directly tackling this issue, it is important to understand the reasons why many people currently do not turn off their computers, thereby unnecessarily wasting electrical energy.

One reason identified by Kuk et al. [1994] is that people find it inconvenient to turn off their computer and then having to wait while it reboots to begin using it again. They prefer to leave the computer on, so that it is immediately available when they wish to begin working again. This rationale was frequently cited as a reason for leaving one's computer on over lunch time. Another reason identified by Kuk et al. was forgetfulness. In their rush to leave work, some people simply forget to turn off their computer. A third reason why many people do not turn off their computers when they are not being used is that people are under the impression that it is bad for the computer to turn it off and on. This belief seems to be relatively widespread, yet there are data which directly contradict it. For example, one study indicated that leaving a computer on for 365 days per year leads to a mean time to failure of approximately 2.3 years [Ullman, 1994]. In contrast, a computer that is consistently turned off during the evenings and on weekends leads to a mean time to failure of 9.6 years! A final reason why people do not turn off their computers identified by Kuk et al. is that some people think that screen savers save energy while their computer is in use. In fact, this is not true, since the only function of such programs is to keep the monitor picture tube from being damaged.

Interestingly, Kuk et al. also found that most people did not have an accurate conception of the electrical energy cost associated with leaving a computer on for 24 hours a day for 365 days. The estimates ranged from $10 to $5,000 but the actually value ranges from $87 to $130, depending upon the model [Newshame and Tiller, 1994]. Perhaps even more importantly, the people who greatly overestimated the actual cost tended to always turn off their computers overnight and on weekends. This shows the impact that perceptions can have on human behavior. But since most people did not have any idea of how much money they are wasting by not turning off their computers, they have no meaningful measure by which they can determine that there is a problem or by which they can regulate their behavior. In short, there is no tangible connection between people's actions and the resulting consequences.

To remedy this problem, different types of solutions would be required for different types of settings, since it is unlikely that a single solution would be universally acceptable. One of the solutions developed by Kuk et al. [1994] was the Power Pig, software which is designed to provide computer users with salient, prompt feedback as to the consequences of their actions and to educate and help shape users' behaviors. As such, it embodies the design principles discussed in the previous section.

Figure 1 illustrates the Power Pig display [Kuk et al., 1994], which is based on an analogy between consuming a great deal of electricity and obesity. This analogy tries to exploit the correlation in North American society between obesity and self-esteem. As Yates and Aronson [1983: 440] put it: "If we can somehow con-

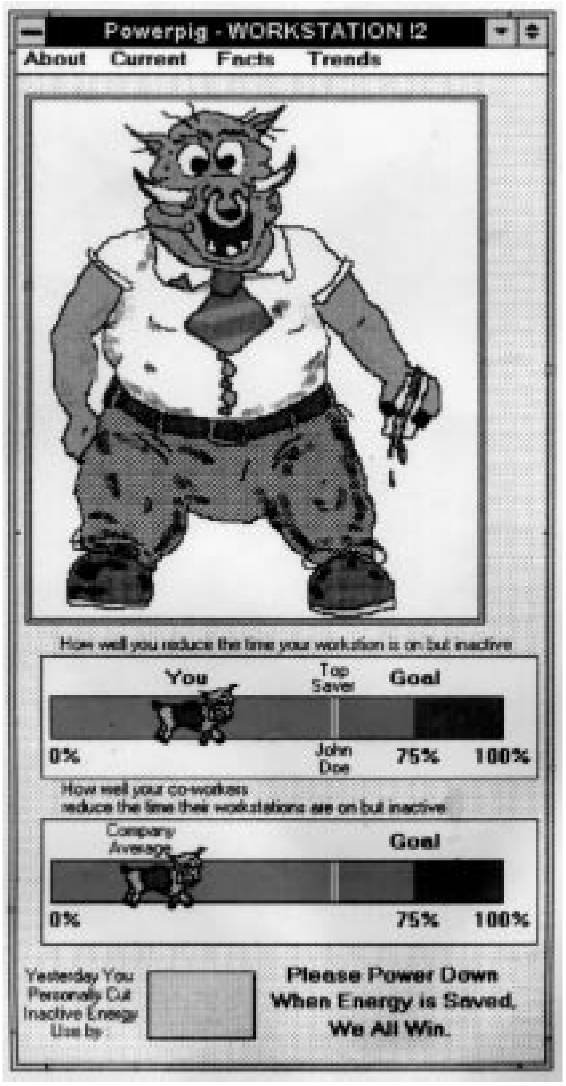

Figure 1 Power Pig display for energy conservation, from Kuk et al. [1994]. See text for description.

vince [consumers] that in the case of energy consumption, consuming less is akin to being slim and trim (which is esteem enhancing) rather than obese, some progress might be made." Thus, Power Pig tries to shape behavior by leveraging people's attitudes regarding obesity and self-esteem. If successful, Power Pig would thereby encourage people to think about energy conservation as something that is attractive and desirable.

As shown in Figure 1, the Power Pig display is divided into four parts. The first part, at the top, is a cartoon drawing of a pig. A number of different images are available, from a fat ugly pig indicating wasteful energy conservation behavior, to a slim, muscular, and attractive pig indicating energy conservation behavior. Frequent updating of this portion of the display provides users with prompt, salient feedback regarding how well they are achieving the desired goal. Note that this portion of the display is personalized in the sense that it reflects the effects of the behavior of a single person. This is an important point because previous research has indicated that the single most important factor in modifying performance in a company was to give each employee a way of developing a standard of their own, so that they can easily evaluate what they consider to be success [Carr, 1993]. Note that the user will not be able to view the more attractive pig images until the desired changes in behavior have been realized, thereby providing some motivation for energy conservation practices.

The second part of the screen, just below the pig cartoon in Figure 1, shows a horizontal bar display with a pig icon. This display is based on the metaphor of a race between the user and the top energy conserver in the entire company (John Doe). In essence, the top conserver serves as a role model, showing that better performance is in fact possible and currently being achieved. Putting the user's current level of performance on the same scale as the role model provides a concrete, personalized frame of reference that can motivate users to change their behavior.

The third part of the screen, near the bottom of Figure 1, also consists of a horizontal bar chart display. In this case, however, the company's average level of performance with respect to a set goal is being shown. The direction in which the pig icon is facing indicates the day to day trend in energy efficiency, with a pig pointing to the right indicating a performance improvement and a pig pointing to the left indicating a performance decrement. Note that this bar display is aligned with, and on a common scale with, the one above. This feature makes it easy for users to see if their behavior has placed them above or below the company average. This aggregate level display is very important because it shows that changes in behavior at the level of individuals can actually have a significant impact on aggregate level performance. One of the biggest obstacles to inducing changes in behavior in some cases is that people have the attitude: "Why should I change my behavior. One person won't make any difference." This portion of the Power Pig display tries to counteract this natural tendency by showing the relationship between individual behavior and performance of the group as a whole.

Finally, at the bottom of Figure 1, there is a digital display which displays the user's own daily efficiency level. This display provides a clear indication of daily changes in a precise, quantitative manner, thereby complementing the graphical displays above it. One can think of this display as the energy conservation "grade" that the user has attained.

In summary, the Power Pig design is based on the following concepts:

- leverage existing attitudes regarding self-esteem
- provide an attractive graphical "reward" that can only be observed once the desired level of behavior has been achieved, thereby improving motivation
- provide feedback about one's own performance relative to that of a role model
- provide explicit goals to be achieved
- provide feedback regarding individual and group performance on a common scale
- take advantage of graphical representation formats that are easy and quick to read.

Collectively, these design features are intended to make it easy and natural for people to adopt changes in behavior that are functional in the sense that they contribute towards solving an important global problem.

4.2. Reducing Photocopier Paper Wastage

Aside from electrical energy, there are other nonrenewable resources that are quickly becoming depleted because of wasteful behavior. One example is that of paper wastage. Long, Ramsahai, Bhujwalla, and Wright [1994] cite sources indicating that the average amount of paper and paper products thrown out, per capita, per year is over 1019 pounds. There are many activities and many products in contemporary society that contribute to this wastage. Arguably, one of the least obvious contributors is the modem office photocopier. However, if one thinks about how frequently photocopiers are used in an enormous number of businesses and academic institutions, the example does not seem so far-fetched. Moreover, if one considers that people frequently throw out at least one wasted photocopy when they use copiers [Long et al., 1994], then the example takes on an even greater relevance. Given the enormous volume, even a very small reduction in the rate of wastage can lead to sizable gains, in absolute terms.

Long et al. [1994] adopted a human factors systems approach to tackle this problem. They began by interviewing photocopier users, and by conducting a task analysis of photocopier usage. Based on these analyses, they learned that the single most important factor that leads to wastage in the use of photocopiers is the fact that people do not know exactly what the copy will look like before they print it out. In other words, there is a lack of feedback for the users of the device. Several examples of the lack of feedback can be given. For instance, sometimes users do not align the document so that the proper material appears in the copy and in the proper orientation. This seems to be more prone to occur when one is using a reduction or enlargement option. The results are that the copy either contains information that is not desired, does not contain information that is desired, or comes out looking crooked. In other cases, partly because of poor labeling and lack of standardization, users sometimes align the document in a direction that is actually orthogonal to the desired direction. Because some photocopiers require that documents be aligned vertically whereas others require that they be aligned horizontally, users sometimes print out a page that only contains part of their document, with the remainder of the page being blank. In all of these cases, users only realize that there is a problem *after* they print a copy. Thus, the fact that users do not have direct feedback as to what the photocopy is going to like before they print it leads to wasteful behavior. Note also that when one is making a large number of copies of a large document, the consequences of an error are especially great. The practical implications of the lack of feedback are compounded by the fact that there is no standard design for photocopiers and that users sometimes have to use unfamiliar photocopiers (e.g., in a library).

Like many other poor designs, people learn to live with these problems. As one person interviewed by Long et al. [1994: 3] observed: "After a while you learn, but that's 20 papers later and 20 papers wasted." Rather than accept this source of paper wastage as an unalterable fact of life, Long et al. tried to address the problem by proposing a design change. Following a systems approach, their goal was to create the conditions that would induce people to naturally engage in the desired behaviors, namely, efficient photocopying, thereby reducing paper wastage.

The most innovative feature of the design proposed by Long et al. was driven by the feedback principle described in the previous section. This led to the suggestion of a display, driven by a scanning device, that would show the user exactly what the photocopy would look like *before* it was printed. Not only could this address the alignment problems described above, but it could also reduce the amount of paper wasted in case the contrast of the copy was inadvertently set at an inappropriate level. As far as we know, this design feature has never been implemented, so that no evaluation of its effectiveness or technical or economic feasibility has been performed. Intuitively, however, it seems clear that the new source of feedback would lead to an enormous reduction in paper wastage. This is a powerful example of how the creative application of a systems approach to human factors can potentially help to address global problems in unique ways.

4.3. Conserving Residential Utility Consumption

Another example illustrating how a systems approach to human factors can help contribute towards solving an important global problem was developed by Hung, Ng, So, and Woo [1995]. The problem they tried to tackle was that of conservation of electricity, water, and gas in the home. Their proposed solution, referred to as SMART meter, takes advantage of the design principle of providing prompt, salient feedback, described in the previous section.

Consider what sources of feedback are available to regulate the amount of energy consumed in residential settings. In condominiums, which charge a flat rate to occupants independent of how much energy they actually consume, there is essentially no feedback. The only piece of evidence one has available is the amount by which one's monthly maintenance fees increase from one year to the next, but, even then, the unique contribution due to increased (or decreased) energy consumption is very difficult to obtain. Homeowners receive a utility bill but only every few months typically. Thus, this source of feedback can hardly be considered to be prompt because of the lag involved between one's actions and feedback regarding its effects. Moreover, utility bills are subject to seasonal variation, and since clear reference points or goals are not usually displayed on the bill, it is difficult to evaluate whether one's conservation behavior is improving or worsening. The other source of feedback that is available in homes is the set of meters that measure electrical consumption, for instance. However, as we shall see below, these meters were not designed with residents in mind, nor with the intent to induce changes in energy consumption behavior.

Is there any evidence to indicate that there is a correlation between the feedback available to residents and the amount of energy they consume? In fact, Hung et al. [1995] found there is very compelling evidence that this correlation is a strong one. For example, in the city of Etobicoke, Ontario, studies have shown that water consumption in households that do not have utility meters was greater than that in homes that have meters by approximately 45%. Similarly, in the province of Alberta, a 10–25% decrease in the consumption of water was observed after the installation of water meters. A third example of the linkage between the availability of feedback and conservation behavior can be found in data provided by Ontario Hydro [1993]. These data show that both electricity and water consumption rates are significantly higher for multiresidential complexes (such as apartment buildings) than for single family households. Although one cannot prove that this is the case, it seems highly likely that this difference arises from the fact that multiresidential complexes typically charge a flat rate for utilities. Hung et al. [1995: 3] correctly observe that, in such cases, "a feedback mechanism is lost. Perhaps, then, the key to solving part of our energy waste problem is to begin treating our costs more as a feedback mechanism rather than as a bill."

As mentioned above, the only source of feedback that is available locally regarding energy consumption are the utility meters one finds in most (but not all) homes. But, as Hung et al. [1995] point out, it is very clear that these meters were not designed for the purpose of energy conservation. First, the location of these meters is not very convenient, making them difficult to access. Gas and electricity meters are frequently located outdoors, whereas water meters are frequently located in the basement or other hard to reach places. Second, as shown in Figure 2, the meters are not very easy to interpret for the average homeowner. For example, some meters have dials that violate conventions because they must be read from right to left. Some dials on these meters rotate in a clockwise direction, whereas others rotate in a counterclockwise direction. Perhaps even more confusing is the fact that some of these meters represent a proportional fraction of the energy used. As a result, users must remember to multiply these values by the appropriate multiplier, whose value may differ from meter to meter. Finally, the units that are used on such meters (e.g., KWH, gallons, cu. ft., in, etc.) are not very meaningful to the typical user.

Third, even if one manages to interpret the meters correctly, the significance of these data is not readily apparent. Without some meaningful reference, it is very difficult to evaluate whether one's energy consumption patterns are wasteful or efficient. This problem is compounded by the fact that a meaningful reference should take into account a number of contextual variables (e.g., season, geographic location, and the number of people in the household). Moreover, users would have to take readings on a regular basis, record those readings, and then perform some computations to determine their consumption rate. Although these activities are within the capacity of many users, the fact that they have to be done by the user without any direct support from the feedback system (i.e., meters) itself makes it less likely that they will be performed.

Clearly, under these conditions, it would require a great deal of effort and initiative on the part of a homeowner to obtain the feedback required to regulate their behavior in conserving energy. Thus, it is not

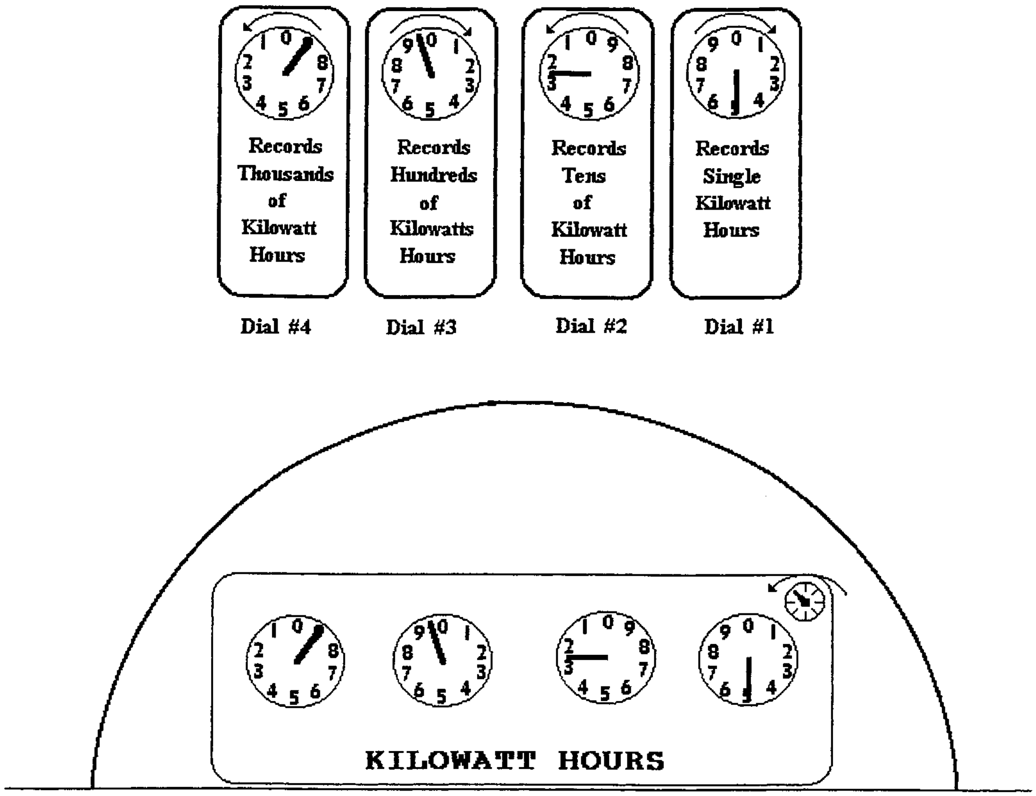

Figure 2 Typical utility meter design, from Ontario Hydro [1993].

surprising that many people do not bother, given the level of effort required. If, on the other hand, the required feedback were available in a form that is easy to interpret and access, then perhaps many more people would use the information to modify their behavior patterns.

This is precisely the idea behind the SMART meter proposed by Hung et al. [1995]. The SMART meter is intended to be an integrated monitoring and metering system that displays the rate of consumption of electricity, gas, and water. It is designed to provide a salient, immediate source of goal-relevant feedback that will make it easy for people to adopt changes in behavior that lead to better conservation of natural resources. The SMART meter addresses many of the limitations of traditional utility meters by adopting the following design features:

- The meter is located in an easily accessible area (e.g., main hallway).
- It provides an integrated display for water, electricity, and gas.
- Information is provided in a graphical format that is easy to interpret.
- Goal-relevant information is provided to the user, including instantaneous rates of usage (where appropriate), cumulative usage totals for regular periods (e.g., daily, weekly, monthly).
- Information that will help users evaluate how well they are doing will also be provided (e.g., historical records showing their performance during the same month of the previous year, average consumption values for the local community).
- Data are presented in terms of monetary units, which are more meaningful to the users.

An example of a SMART meter screen is provided in Figure 3.

As a result of these design features, the SMART meter is intended to provide a bridge between the user's actions and the conservation goals that are desired. By promptly showing the effects of one's behavior on the achievement of desired goals in a comprehensible manner, it should be much easier for users to adopt the required changes in behavior. Thus, the SMART meter provides another example of how it may be possible to induce functional behaviors through the clever and

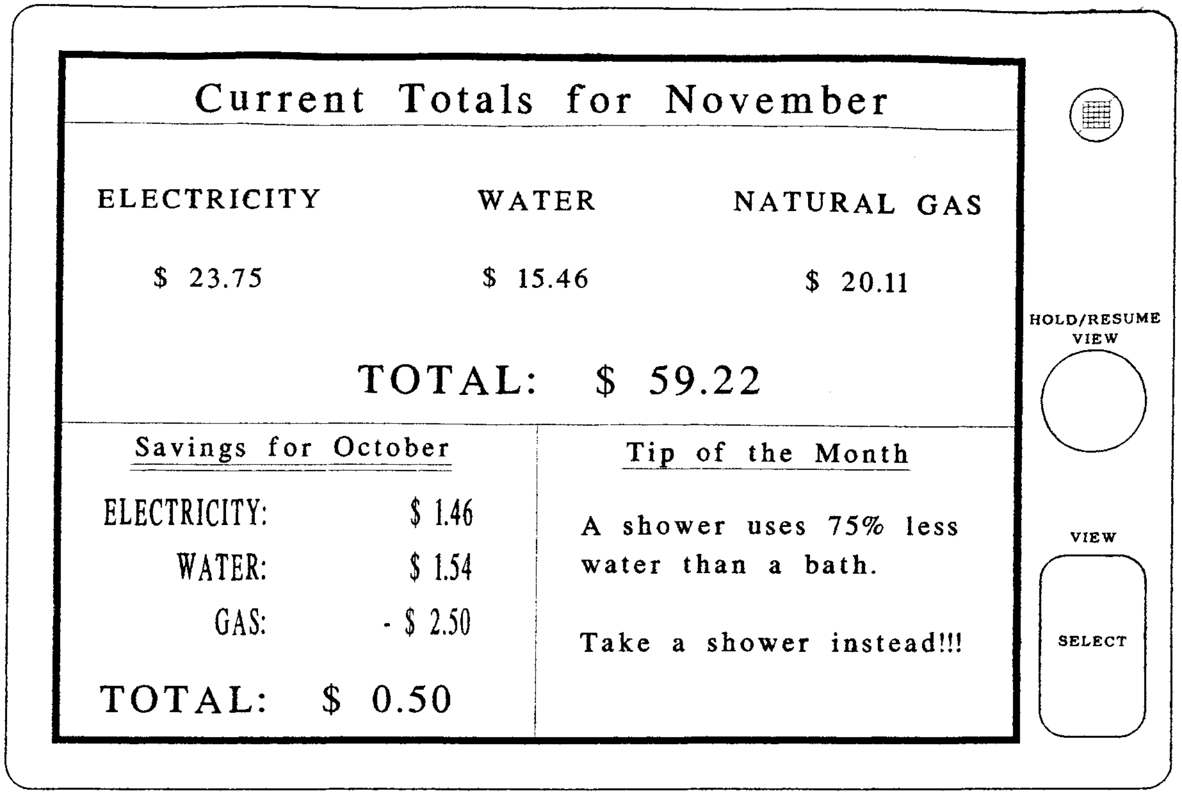

Figure 3 Example of SMART meter display, from Hung et al. [1995].

innovative instantiation of human factors design principles.

4.4. Reducing Water Wastage From Faucets

Water is essential to human life. Although in North America, we generally take a clean and plentiful supply of water for granted, there are many parts of the world that have suffered the dire consequences of not having enough of this natural resource available to them. Unfortunately, the world's water supply is being depleted at an increasing rate. According to Grolier [1993], in 1993, the annual global water withdrawal was approximately 1,700,000,000,000 gallons per day, or 2,400 cubic km per year. This rate is predicted to increase to 14,500,000,000,000 gallons per year, or 20,000 cubic km per year, which greatly exceeds the net annual flow of all of the rivers in the world. Currently, 10% of this consumption rate can be attributed to domestic usage, thereby making reduction of water wastage in homes a worthwhile goal.

Light, Rajenthiram, and Schwartz [1995] addressed a subset of this goal, namely the reduction of water wastage from faucets. Faucets account for 12% of the total indoor consumption of water in the United States [Shrubsole and Tate, 1994], thereby justifying this choice of focus. Light et al. observed how water faucets are used and learned that much of this wastage occurs because people sometimes leave the water running for extended periods while they are attending to completely unrelated activities. Frequently, this arises because people are interrupted, once they already have the faucet running, and their attention is required elsewhere (e.g., a phone call). Instead of turning off the faucet during this interruption, people just leave the water running, thereby wasting a significant amount of water. Light et al. found that there seem to be two main reasons for this behavior. First, people seem to underestimate the amount of water that is consumed while they attend to other activities. This probably arises from the fact that there is no immediate, salient feedback that they can use to develop an accurate perception of the implications of their behavior. Second, people consider the task of turning the water back on to be an annoyance because they usually have to readjust the flowrate and temperature of the water to their respective desired settings. This slight annoyance seems to cause people to "take the path of least effort," which in this case means leaving the faucet on and wasting water, as a result.

Light et al. [1995] developed a design proposal to address this problem based on the idea of behavior-shaping constraints. The goal of their design was to induce people to save water by having them actively perform an action to keep the water on, and then have the water cease from flowing, as soon as people leave the area of the faucet. Their proposed solution was to connect the faucet to a foot pedal that would control the water flowrate. When the pedal is depressed, there would be flow, but as soon as the user's foot is removed from the pedal, the flow of water would stop automatically. In the meantime, both the temperature and flowrate of the water would be kept constant, so that when the pedal was depressed again, users would not have to readjust either of these settings. Instead, they could essentially pick up from where they left off.

There are several advantages to this proposed design. First, it takes very little effort to depress the pedal to engage the faucet. Because the pedal is activated by one's foot, the hands are free to perform the desired tasks. Second, the design makes it very difficult for people to waste water, when they are interrupted by other activities. As soon as the user leaves the faucet area, the flow of water ceases. One could say that the design is "enforcing" the desired change in behavior. Third, the foot pedal design overcomes the problem of having to readjust the temperature and flowrate upon returning from the interruption. Thus, it addresses one of the disadvantages of many existing faucet designs. Fourth, the proposed design could also address water wastage resulting from the fact that people fail to completely close the tap, thereby having water drip from the faucet. Because the foot pedal is a discrete control (on or completely off), dripping should not occur and water should be conserved, as a result. Therefore, the design proposed by Light et al. is a prototypical example of applying the principle of behavior shaping constraints to change human behavior in a functional direction, thereby trying to ameliorate a global problem.

4.5. Summary

As mentioned earlier, the examples presented in this section are not intended to be final designs. Details with respect to cost and technical implementation have not been thoroughly examined. Furthermore, prototypes have not been built, so the value of the proposed designs has not been empirically established. However, these design examples do show how it is possible to apply a systems approach to human factors to global problems. In each case, the application of the principles discussed in the previous section led to an innovative, creative idea that is intended to induce behavior changes that are functional with respect to contributing towards the solution of a global problem.

The problems addressed by these designs represent a tiny fraction of the global problem in question. However, if more products were designed according to such principles and with the same goal in mind, then the aggregate contributions could amount to substantial improvements. In essence, the examples presented in this section provide some concrete flesh to the conceptual developments of Nickerson [1992] and Moray [1993, 1994]. Hopefully, this will spark others to apply these ideas, with the end result that designing products to shape human behavior in a fashion that contributes to the amelioration of global problems will become a commonplace occurrence.

5. CONCLUSIONS

The discipline of human factors has traditionally been concerned with a wide variety of problems that require knowledge of human capabilities and limitations. However, the knowledge base that has been developed by the discipline has rarely been applied to global problems that contemporary society is facing. Thanks to the recent work of Nickerson [1992] and Moray [1993, 1994], this is now beginning to change. These authors have convincingly argued that many global problems have a strong human component and, therefore, that the discipline of human factors has a unique (but certainly not privileged) role to play in the interdisciplinary effort that is required to deal with these challenging problems.

This paper has reviewed some of this work, focusing on a systems approach to applying human factors to global problems. Two design principles, behavior-shaping constraints and salient, immediate feedback, were proposed as powerful ways to induce people to change their behavior patterns in a functional direction, thereby contributing towards the solution of the pressing problems facing contemporary society. Several applications of these design principles were presented, not as final solutions, but rather as illustrations of the type of impact that the discipline of human factors can have.

While only a few applications were presented, it is important to note that the potential contribution of human factors is much broader than these examples illustrate. Nickerson [1992] includes the following problems that can be addressed by human factors in a changing world:

- economics, industry, and productivity
- energy
- environmental change
- education and training

- transportation
- space exploration
- biotechnology
- information technology
- person–computer interaction
- work
- decision making and policy setting
- quality of life

To realize the vision put forth by Nickerson requires that human factors engineers broaden their traditional view of their own discipline. It also requires that those in other disciplines recognize the unique and significant contribution that human factors can play in dealing with the challenges of contemporary society. In either case, the demands are strong, as Nickerson [1992: 372–373] points out:

> The most significant need for the future, in my view, is for a willingness to adopt a more reflective attitude toward the world and our places in it than we have tended to take in the past. We must be willing to rethink some of the tacit assumptions that we tend to make. We must be more explicit with ourselves regarding our personal values and more prepared to examine our deepest beliefs and live by those we find compelling. We cannot afford to let our attitudes and values be shaped by the image makers and hucksters of the world. We must learn to think for ourselves and to work for goals that reflection has convinced us are worthwhile and not only for things that someone else has persuaded us we ought to want. The world is rapidly becoming too small to permit us to survive unless we find a way to become more rational and better able to contain our destructive instincts, even as we find ever more powerful ways to express them.

The challenge put forth by Nickerson is onerous indeed, but have we any choice but to accept it?

ACKNOWLEDGMENTS

The writing of this paper has been supported in part by a research grant from the Natural Sciences and Engineering Research Council of Canada. I would like to thank the students in IND 216F (Introduction to Ergonomics for Engineers) in 1994 and 1995 in the Department of Industrial Engineering at the University of Toronto for their creative examples, and for the enthusiasm they showed in applying human factors to global problems. A heartfelt thank you also to Neville Moray for inspiring me to work on this topic.

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