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DESCRIBING THE HUMAN IN MODELS FOR SYSTEMS DESIGN

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EXECUTIVE SUMMARY

This paper raises some general issues related to the gap which is perceived to exist between the human factors knowledge base and engineering design, particularly when dealing with decision making during the earliest stages of system development. The contribution of modelling to bridging this gap is discussed, as are problems associated with incorporating human factors knowledge into the type of computational models favoured by the engineering and operations research (OR) communities. Despite well recognised difficulties, a number of areas where this gap has been bridged successfully can be cited. A particular example where human factors knowledge has been incorporated into a computational model, borrowed from the OR and industrial engineering worlds, is discussed in detail. The model, called LOCATE, is the heart of a computer-aided design tool intended for a class of workspace layout problems where the emergent properties due to human capabilities and characteristics can dominate system performance.

LOCATE attempts to incorporate a wide range of knowledge about human communication within the visual, auditory and spatial domains, by augmenting a method already well known in the OR and industrial engineering environments. The components of this augmentation provide a toolbox for incorporating a range of human characteristics into a computational model. Through the introduction of various transformation functions, human factors data may be treated in ways which are consistent with a probabilistic assessment of system performance. LOCATE was developed to handle a particular scale of workspace layout problem, that is, workspaces where the geometric scale is within the intermediate to far range of human sensory performance. At this scale, human characteristics of vision, audition, movement, and reach cannot be ignored. Examples of this type of problem include the layout of office or factory floorplans, command and control centres and air traffic control facilities.

The primary emphasis in LOCATE is to provide a tool which allows a rapid and comprehensive assessment of a given workspace layout, through the calculation of a figure of merit which represents the overall *goodness* of the configuration. While the LOCATE cost function is compatible with the application of optimisation techniques, its use purely as an assessment tool should not be underestimated. While machine solutions can be extremely useful in establishing an initial set of possibilities, most optimisation methods do not guarantee to find the global minimum. Even if the global minimum was computationally achievable, the machine solution is still not necessarily the best configuration for the application. Other factors, not modelled in LOCATE, may have to be considered. Hence, the ability to allow operator intervention should be built into any design/assessment aid of this type. A systems evaluation tool should be able to accommodate the assessment of individual configurations, regardless of the method used to establish their configuration, as well as supporting machine-aided solutions.

As the information required to run a LOCATE analysis is the same type of information that is required for a rigorous HF assessment using traditional techniques, the overhead associated with LOCATE's use comes primarily from the software user-interface rather than from the need to support special data gathering. This is demonstrated in the ship's bridge analysis, where the input data for LOCATE were drawn from various reports which described the earlier, non-machine-aided, evaluation. Hence, LOCATE is offered as a demonstration that it is possible to bridge the gap between human factors knowledge and engineering design, in a manner which is consistent with the requirements for early intervention in the systems design process, and that modelling can provide the framework for an integrated approach to system performance assessment.

ABSTRACT

This is the text of a paper presented at The Institute of Management Science/Operations Research Society of America (TIMS/ORSA) Conference, 27-29 April 1992. An abstract of the paper appears in the proceedings. The paper raises some general issues related to the gap which is perceived to exist between the human factors knowledge base and engineering design, particularly when dealing with decision making during the earliest stages of system development. The contribution of modelling to bridging this gap is discussed, as are problems associated with incorporating human factors knowledge into the type of computational models favoured by the engineering and operations research (OR) communities. Despite well recognised difficulties, a number of areas where this gap has been bridged successfully can be cited. A particular example where human factors knowledge has been incorporated into a computational model, borrowed from the OR and industrial engineering worlds, is discussed in detail. The model, called LOCATE, is the heart of a computer-aided design tool intended for a class of workspace layout problem where the emergent properties due to human capabilities and characteristics can dominate system performance.

Keywords: workspace layout human modelling optimisation LOCATE

INTRODUCTION

Human factors specialists have long argued for the right to be involved in the systems design process from the earliest stages of concept development and preliminary design (Moore, 1984; Marshall, 1991). Yet the human factors community has relied heavily on a reductionist approach, using human experimentation as a problem solving paradigm, and have not always been well equipped to provide timely answers during the earliest stages of project development (Meister, 1984; McBride, Owens, and Goodman, 1984; Alluisi, 1986; Meister, 1989; De Greene, 1990). While human factors data abound, the knowledge base is often fragmented, deals with a single variable at a time, is difficult to generalise, and lacks a suitable framework for integrating these data with the engineering design process. As a result, human factors data have often been ignored in making critical design decisions (Simon, 1987), particularly during the initial stages of a project. The gap between the human factors knowledge base and engineering design needs to be bridged. Models represent one class of tools which can provide a common framework for the integration of knowledge from all engineering disciplines, including human factors engineering.

Models deal with ideas in abstraction, and can be applied when hardware for experimentation and simulation, using human subjects, is absent. During concept development and preliminary design, system models which incorporate aspects of both hardware and human performance can provide a mechanism for applying human factors knowledge to engineering design. Speight (1984) points to the widespread use of operations research (OR) techniques as decision aids in military equipment procurement in the United Kingdom, and describes the move away from a reductionist approach to an assessment of overall system capability. He suggests that human factors people should take note of this trend, if they want their contributions to be included in decision making. He argues for the active participation of human factors people within the OR community so that the human element of systems models can be adequately represented.

If one adopts a loose definition of the word *model*, then models of the human abound. Most are purely descriptive, with relatively few suitable for integration with the engineering design process. Yet, despite the difficulties of providing analytical descriptions of the human and human behaviour, there are many examples of the successful incorporation of human factors knowledge within computational models. Notable among these are biomechanical and anthropometric models, models for human vision and audition, and task network models for performance and workload prediction (for a summary of human performance modelling, see McMillan, Beevis, Salas, Strub, Sutton, and Van Breda, 1989; and Elkind, Card, Hochberg, and Huey, 1989). While it might be justly claimed that many, or even most, human models are crude representations of the richness and

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variety of human behaviour, they may provide an adequate first-order representation from which the emergent properties (Checkland, 1981) of a human-machine system can be captured. Emergent properties are, by definition, evident only when the system components are allowed to interact. For example, human communication, both between humans and between humans and machines, can be classified as an emergent property. When the emergent properties of a system are as important as the properties of the individual components, then modelling at the systems level, albeit with first-order representations of the individual components, may provide greater insight into system performance than studying some components (usually the hardware) in isolation, while ignoring others (often the human elements).

Typically, human factors data are not gathered, or presented in the literature, with the requirements for modelling in mind. Models generally make use of data in the form of analytical expressions, probabilities, and statistical distributions. Probability-based analyses are particularly useful when performing trade-off studies during concept development and equipment selection. Human factors data, on the other hand, are often incompatible with this type of approach. Many of the human factors standards and guidelines present data in the form of recommended values, with upper and lower limits (e.g. minimum, comfort and maximum temperatures for crew compartments), rather than probabilities (Erickson, 1984). Once one deviates from the recommended range of the data, outcomes are uncertain. Yet generally human performance does not fail catastrophically when a recommended limit is exceeded by some small amount. However, the question of how much degradation might be expected from such a deviation is seldom answered. Although the nature of classical human factors experiments make this type of generalisation difficult (for example see, Meister, 1989; Simon, 1987), sometimes human factors data can be recast in probabilistic terms for aiding operational decision-making.

This paper describes an attempt to incorporate human factors knowledge within an analytical model intended to provide assistance to designers in the layout of various human and machine elements within an available floorspace. The model, called LOCATE (Hendy, 1989), attempts to incorporate a wide range of knowledge about human communication within the visual, auditory and spatial domains, by augmenting a method already well known in the OR and industrial engineering environments. The components of this augmentation provide a toolbox for incorporating a range of human characteristics into a computational model. Through the introduction of various transformation functions, human factors data may be treated in ways which are consistent with a probabilistic assessment of system performance. LOCATE was developed to handle a particular scale of workspace layout problem that appears to have been neglected, that is, workspaces where the geometric scale is within the intermediate to far range of human sensory performance. At this scale, human characteristics of vision, audition, movement, and reach cannot be ignored.

Examples of this type of problem include the layout of office or factory floorplans, command and control centres and air traffic control facilities. LOCATE can handle problems of different scope, but its major advantages are seen when it is human, rather than machine, characteristics which determine system performance.

During development, LOCATE was tested against several simple layout problems as part of the validation process (Hendy, 1984). Subsequently, LOCATE was used to analyse a complex real world problem, namely, the evaluation of a number of ship's bridge configurations (Hendy, Berger, and Wong, 1989). The results of the LOCATE analysis were compared to recommendations made during an earlier evaluation, using more conventional human factors techniques. The conclusions drawn from the LOCATE analysis were consistent with the earlier evaluation so far as the major issues were concerned. However, the LOCATE analysis provided a more integrated approach to the evaluation, and allowed a more comprehensive assessment of issues such as visual monitoring and the quality of auditory communication. The development of LOCATE is described in detail elsewhere (Hendy, 1984; Hendy, 1989). Therefore, after an abbreviated introduction to the mathematical form of LOCATE, this paper focuses specifically on those aspects which are related to the incorporation of descriptions of human capabilities and limitations into the modelling environment.

THE *LOCATE* MODEL

When the physical arrangement of items of equipment and personnel affects system performance, the relative location of each component within the workspace becomes a critical design issue. Workspace arrangement affects access to visual information, the quality of voice and other auditory communications, the pattern of movements within the workspace, and the time taken to traverse the paths between various points within the space. Such a problem quickly becomes intractable to solution by manual methods (Apple, 1977) as the number of elements and the number of interactions increase. Machine-aided design provides a method for handling the complexity of such problems, as well as providing the potential for extending the scope of the problem-solving domain, through: access to human factors data bases; the use of implicit knowledge contained in embedded models of human behaviour; and the dissemination of human factors knowledge through computer-aided design packages and expert systems (Wilson, 1984).

Previous attempts to formulate analytical solutions for this type of problem have generally been based on classical link analysis. As so often happens, models borrowed from the physical sciences, OR and engineering are either inappropriate in their basic form for modelling human characteristics, or they provide such a sparse representation of human capabilities as to be useless. Procedures based on classical link analysis assume all knowledge about a given interaction is vested in the *length* of the link between the interacting elements. Typical of these methods ALDEP, CORELAP, CRAFT (Francis and White, 1974), WOLAP (Rabideau and Luk, 1975), PLANET (Apple, 1977) and DISCON (Drezner, 1980) all compute their cost functions from the weighted sum of distances between workspace element centres. Such link length calculations emphasis the transmission path between elements, rather than the properties of the elements themselves as sources and receivers of information. Link length alone captures little of interest about human behaviour at the scale of problem for which LOCATE was intended.

LOCATE is concerned with the location of elemental workstations within a continuous solution space (allowing for translations in x and y together with rotations $\emptyset$). Although not computationally limited to two Cartesian dimensions, LOCATE has not been extended into the third translational dimension as yet (such an extension is planned for the future development of this tool). A fundamental feature of the LOCATE model, and that which distinguishes it from other methods, is the concept of *Link Strength Functions* (*LSFs*). *LSF*s provide transformations which turn link length and link orientation data into information about visual, auditory and spatial interactions between pairs of elemental workstations. In other words, it is through the *LSF*s that transmission path information is transformed into the realm of the workspace elements themselves, to provide descriptions of the potential for visual, auditory and spatial communications. Within the spatial domain, LOCATE deals with both tactile relationships (i.e. reach to other operators and objects) as well as with the distance travelled between various points in the workspace. *LSF*s are chosen to represent human and machine properties which can be characterised by distance- and angular-dependent relationships, for example: preference for locating visual displays with respect to the operator's normal direction of gaze; sound pressure patterns of audible alarms, voice communications and displays; or operator reach envelops. *LSF*s are used to represent both the strength of the information originating from the source, as well as the strength of the information received by the observer/receiver.

In LOCATE the *strength* of a given communication link modulated by various attenuating effects, due to the presence of obstructions in the workspace, provides a measure of link *quality*. In this sense, link strength is a dimensionless number (in the range 0 to 1) representing, on a scale of *goodness* or *utility*, the relative performance of the unobstructed flow of information either originating at the source or as received at the destination. The underlying performance criterion could be error rate, probability of detection, etc. Similarly for link quality, but now obstructions are taken into account.

Link quality is calculated as follows:

$$q(i,j) = r(i,j)\, s(i,j) \prod_{h} \alpha(i,j,h) \prod_{k} \beta(i,j,k),$$

where,

a. $q(i,j)$ is the *quality* of the (i,j)th link $(0 \leq q(i,j) \leq 1)$;

b. $s(i,j)$ is the *strength* of the information originating at the jth source $(0 \leq s(i,j) \leq 1)$;

c. $r(i,j)$ is the *strength* of the information which, if unattenuated by obstructions, would be received by the ith receiver $(0 \leq r(i,j) \leq 1)$; and

d. $\alpha(.)$ and $\beta(.)$ are *transmission* factors (in the range 0 to 1) that represent the attenuation to the (i,j)th link by the elemental and fixed obstructions in the workspace (note: *elemental obstructions* are associated with the individual workspace elements while *fixed obstructions* exist within the workspace itself - it is convenient for computational purposes to treat the attenuation due to fixed and elemental obstructions separately).

The values $r(i,j)$ and $s(i,j)$ are further split into distance dependent and angle dependent components (denoted by R and Ω subscripts respectively) which are combined as follows:

$$r(i,j) = r_{R}(i,j)\, r_{\Omega}(i,j), \text{ and}$$

$$s(i,j) = s_{R}(i,j)\, s_{\Omega}(i,j).$$

In combining link strengths independence has been assumed. This is not a limitation of the mathematical formulation, and an interaction term could be introduced if required. This is a consideration for the future development of LOCATE.

The overall system cost function has the following general form:

$$J = \sum_{i}\sum_{j} \kappa \{1 - q(i,j)\}\, p(i,j),$$

where,

a. J is a measure of the system *cost*;

b. $p(i,j)$ is the *priority* associated with the (i,j)th link; and

c κ is a *weight* for each domain of communication (visual, auditory, tactile or movement).

The composite cost function is evaluated by summing over each domain of interest. Again, independence is assumed, and while not computationally limited to a linear representation, the advantage of using more complicated combining rules is yet to be established. This cost function can then be used to produce a figure of merit for any given configuration, or it can be operated on by an optimisation routine to produce a *best* layout subject to the constraints of the workspace. Typical constraints for the layout problem include the requirement that elemental workstations do not overlap, the presence of fixed elements, and bounds caused by the physical extremities of the workspace. Optimisation in the continuous solution space requires, in general, the minimisation of a non-linear cost function, one that has to be numerically differentiated, and is subject to a set of non-linear constraints. Despite the complexity of this problem, successful optimisations have been carried out, for up to 10 element problems, using third-party software from the Numerical Algorithm Group (Hendy, 1984).

LINK STRENGTH FUNCTIONS

The heart of LOCATE is the *LSF*. Values for $r(i,j)$ and $s(i,j)$ are obtained from *LSF*s appropriate to the domain in which each interaction is formed. Generally, *LSF*s for a given pair of workspace elements will be different for each domain of interest. Potential mathematical forms for the *LSF*s, and some of the processes they might represent, include: the complementary error function (cumulative proportion of a subject population achieving various reach distances); a linear function (movement time at constant speed); the Gaussian Normal function (an approximation to the directional properties of an audio transducer); the Butterworth function (visibility of recessed or baffled displays); a constant function (omnidirectional auditory source); an inverse power function (speech intensity versus distance) or an exponential function (extinction of light caused by atmospheric absorption or scattering). Examples of these functions can be found in Appendix 1. To be compatible with the need to optimise in a continuous solution space, the *LSF*s should be continuous, and have continuous first and second derivatives. It is emphasised that the functions shown in Appendix 1, merely represent the basic building blocks of LOCATE. Any other function, having the properties of continuity and double differentiation, can be added as required.

For the purposes of illustration, Figure 1 shows a set of *LSF*s that could describe the interaction of a human operator with a visual display. The (v) superscript denotes the visual domain of communication. In Figure 1, the $R_{\Omega}^{(v)}$ function weights the central 30° of the receiver's visual field most highly (assumed in this case to be a human observer), with an increasing penalty for information displayed outside the central region. Such a function reflects the guidelines, for the recommended location of critical displays and warning signals, contained in human factors references (see, for example, Woodson, 1981; MIL-STD-1472C, 1984). Generally, the readability of a display, as a function of distance, depends on the display characteristics only (character size, contrast ratio, display luminance etc.). These factors are represented cumulatively in the source function $S_R^{(v)}$. This function could be chosen to represent the probability of correctly recognising characters of given size and contrast ratio, as a function of distance, under the prevailing levels of illuminance.

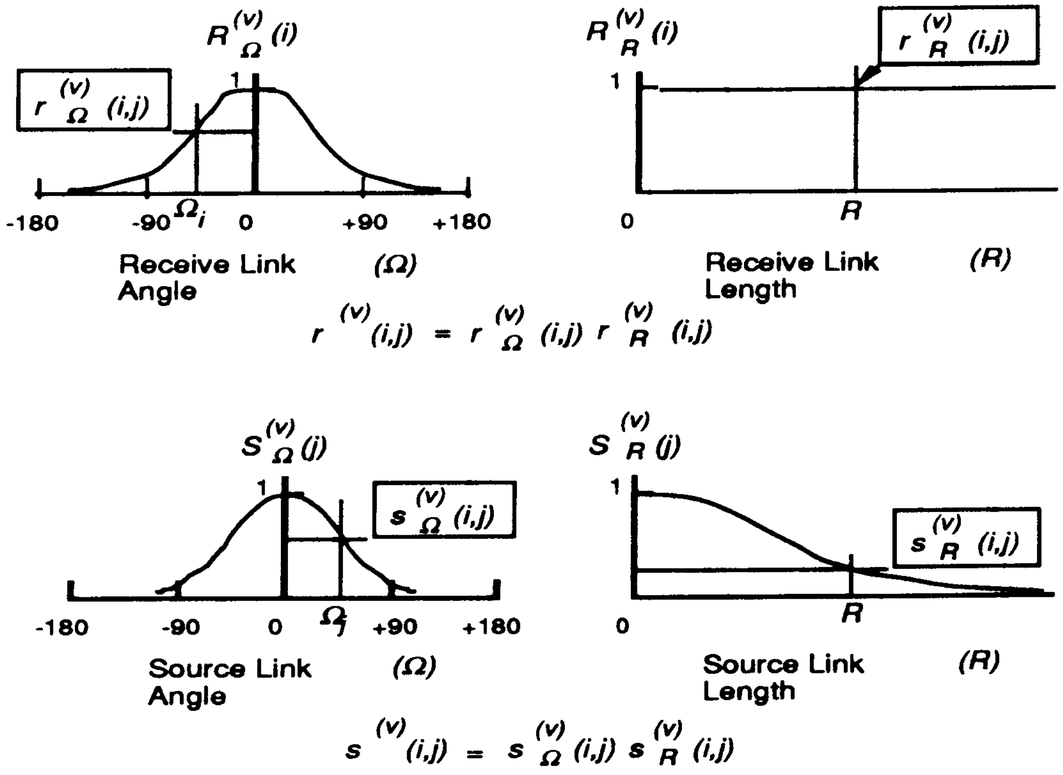

Figure 1. *Typical link strength functions* (LSFs) *for a visual communication link. These functions represent the interaction of a visual source of information of given character size and directional properties, with a human observer having no visual defects and who places a high utility on information appearing in the central 60º of the visual field. (from Hendy, 1989)*

In Figure 1 the receiver function $R_R^{(v)}$, which is shown to be independent of distance, contains no performance penalty. If, however, there were factors acting in the transmission path that were likely to cause a degradation in the quality of displayed information (e.g. dust or haze which would cause scattering or absorption of light, a reflecting surface which produces glare), then $R_R^{(v)}$ could be modified to reflect this situation. Alternatively, an additional function could be introduced into

LOCATE, specifically to model such transmission path effects. If the receiver possesses some characteristic which restricted the range of useful vision (e.g. a visual defect such as myopia, or the use of some indirect viewing device such as a night vision aid) then $R_R^{(v)}$ would be chosen accordingly. Finally, the angular properties of the display are represented in the function $S_\Omega^{(v)}$. In Figure 1, this function represents a display where off-axis viewing is associated with a performance decrement (a liquid crystal display, a beaded front projection screen, the change in aspect ratio of letters on a screen etc.). In each case the *LSF*s provide a mapping from the metrics of the problem domain (i.e. distance and orientation) into the domain of human performance.

TABLE 1

Parameters of the *LSF*s Used in the Evaluation 5 Ship's Bridge Layouts. The functions and their arguments are defined in Appendix 1 (from Hendy, 1989).

Link Strength Function		*Receive Function**			*Source Function**		
		Type	*Arg1*	*Arg2*	*Type*	*Arg1*	*Arg2*
Visual							
Human elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Butterworth	4.0	1.571	Constant	1.0	n.a.
Chart table	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Gaussian	0.0	0.785	Constant	1.0	n.a.
Radar	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Gaussian	0.0	0.262	Constant	1.0	n.a.
Other elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Auditory							
Human elements	R	Constant	1.0	n.a.	Butterworth	5.0	78.0
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Other elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Distance							
Active elements	R	Constant	1.0	n.a.	Linear	630	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.
Dummy elements	R	Constant	1.0	n.a.	Constant	1.0	n.a.
	Ω	Constant	1.0	n.a.	Constant	1.0	n.a.

* Parameters, with the exception of nondimensional numbers, are in radians for angular (Ω) functions and in inches for distance (R) functions.

To extend this illustration, consider the ship's bridge evaluations (Hendy, et al., 1989). For this study, *LSF*s were chosen to represent characteristics in the visual, auditory and distance domains. The parameters of the *LSF*s are shown in Table 1. Butterworth functions with sharp cutoffs at 90° (1.571 radian) were chosen to model the range of acceptable head movements for visual monitoring. Gaussian functions were chosen to control the absolute (hence the introduction of dummy elements to provide an origin of reference) orientation of the chart table and the radar console (preference for forward facing layouts), because of their strong lobe-like shape when plotted in polar coordinates. A Butterworth function, with a sharp cutoff at 1.98m (78 inches) was selected to model the range of distances over which normal voice communication might be expected under the prevailing noise levels of the bridge environment. A simple linear penalty function was chosen for distance relationships between all active elements. A more detailed discussion of the rationale for the choice of parameters, and the assumptions on which each choice of function is based, can be found in (Hendy, et al., 1989) and (Hendy, 1989).

MODELLING OBSTRUCTIONS

While the *LSF*s provide a description of the potential for inter-element communications, obstructions present in the workspace may interfere with these interactions. Obstructions are usually thought of as causing an *all or nothing* disruption to information flow. Such discontinuities are generally incompatible with the requirements for optimisation in the continuous solution space. Hence, continuous, and twice differentiable, attenuation functions are used in LOCATE to approximate interruption to the transmission of information, attributable to the presence of obstructions. Transmission factors $\alpha(.)$ and $\beta(.)$ are evaluated along the direction of the link vectors as follows:

$$\alpha(.),\ \beta(.) = 1 - \max\{F_h(x',y')\},$$

where $F_h(x',y')$ is a continuous twice differentiable attenuation function, representing the characteristics of the hth obstruction, and (x',y') are the coordinates of the local axis system for the hth obstruction function. The transmission factor is evaluated as the maximum value of this function, along the direction of the link vector. In general, $F_h(x',y')$ will be different for each domain of communication. While it might be expected that a horizontal section through $F_h(x',y')$ would generally match the footprint of the elemental workstation in the xy plane, this need not always be the case. As an example, auditory links might involve acoustic shadowing, therefore, the shape of the attenuation function may not be the same as the physical shape of the item causing the obstruction.

A general class of function, having the required properties of continuity, with well-behaved first and second derivatives, is of the form:

$$F(u,v) = \frac{1}{1 + u^{2n} + v^{2n}}$$

for rectilinearly shaped obstructions and

$$F(u,v) = \frac{1}{1 + \{(u^2 + v^2)/r^2\}^n}$$

for elliptically shaped obstructions. By an appropriate choice of scale factors (i.e. $x' = a_h u$ and $y' = b_h v$) functions of any *major:minor* axes ratio can be represented. Note that as n approaches infinity, $F_h(x', y')$ approaches the binary response (i.e. either 1 or 0). These are the only shapes modelled in the current version of LOCATE.

DISCUSSION AND CONCLUSIONS

The main theme of this paper stems from a perceived gap between the human factors knowledge base and engineering design. It is argued that modelling is one method for bringing together the knowledge from many fields, including human factors, within a unifying framework. Despite many well-recognised problems in translating much of human factors knowledge into a form which is suitable for modelling, many successes can be cited. One attempt at adapting information related to human communication in the visual, auditory and spatial domains, for this purpose, is discussed briefly. A model, called LOCATE, is described which borrows a method from the OR and engineering toolboxes, but augments it with a number of devices to allow for the incorporation of human data. A general outline is given of the two main devices used to accomplish this goal in LOCATE, namely, *link strength functions,* and *attenuation functions* which represent the effects of various obstructions within the workspace. Together, these functions provide the necessary mapping from the metrics of the problem domain (i.e. x, y, and $\emptyset$) into the domain of the human factors knowledge-base. Using standard mathematical functions, a range of human characteristics can be described, at a level of description which captures important emergent properties of the system.

The primary emphasis in LOCATE is to provide a tool which allows a rapid and comprehensive assessment of a given workspace layout, through the calculation of a figure of merit which represents the overall *goodness* of the configuration. While the LOCATE cost function is compatible with the application of optimisation techniques, its use purely as an assessment tool should not be underestimated. While machine solutions can be extremely useful in establishing an initial set of possibilities, most optimisation methods do not guarantee to find the global minimum. Even if the global minimum was computationally achievable, the machine solution is still not necessarily the best configuration for the application. Other factors, not modelled in LOCATE, may have to be considered. Hence, the ability to allow operator intervention should be built into any design/assessment aid of this type. A systems evaluation tool should be able to accommodate the assessment of individual configurations, regardless of the method used to establish their configuration, as well as supporting machine-aided solutions.

As the information required to run a LOCATE analysis is the same type of information that is required for a rigorous HF assessment using traditional techniques, the overhead associated with LOCATE's use comes primarily from the software user-interface rather than from the need to support special data gathering. This is demonstrated in the ship's bridge analysis, where the input data for LOCATE were drawn from various reports which described the earlier, non machine-aided, evaluation. Hence, LOCATE is offered as a demonstration that it is possible to bridge the gap between human factors knowledge and engineering design, in a manner which is consistent with the requirements for early intervention in the systems design process, and that modelling can provide the framework for an integrated approach to system performance assessment.

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Appendix 1

Examples of *LSF* Formulae

Constant

$$F(u) = Arg1$$

Butterworth

$$F(u) = \frac{1}{1 + 3\,(u/Arg2)^{2Arg1}}$$

Linear

$$F(u) = \{(Arg1 - u)/Arg1\},\ u \geq 0$$

Gaussian

$$F(u) = \exp -\{((u - Arg1)^2)/2Arg2^2\}$$

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Hendy, Keith C.

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This paper raises some general issues related to the gap which is perceived to exist between the human factors knowledge base and engineering design, particularly when dealing with decision making during the earliest stages of system development. The contribution of modelling to bridging this gap is discussed, as are problems associated with incorporating human factors knowledge into the type of computational models favoured by the engineering and operations research (OR) communities. Despite well recognised difficulties, a number of areas where this gap has been bridged successfully can be cited. A particualr example where human factors knowledge has been incorporated into a computational model, borrowed from the OR and industrial engineering worlds, is discussed in detail. The model, called LOCATE, is the heart of a computer-aided design tool intended for a class of workspace layout problem where the emergent properties due to human capabilities and characteristics can dominate system performance.

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