Chapter 11 – An Application of Human Factors in Life Support Equipment and Emergency Egress

by

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INTRODUCTION

Our world is filled with thousands of devices, tools, machines and products which when assembled into functional units form systems. By definition a system is a set of elements developed to achieve an objective. A well designed system considers the relations amongst the elements and the boundaries around the elements to provide for the proper considerations of the interaction of the elements to the overall objective. Generally systems have a defined input, process and output.

In terms of the design, operation and control, systems range from very simple to very complex. In many industrial sectors, these systems can range in type from manual to mechanical to finally automatic. In order for these systems to achieve their optimal level of performance they must at sometime interface with humans and therefore the human becomes an important element in the total system. Many people would argue that the human may be the most important element in the system and that the system must "fit the task to the human". Fitting the task to the human is a phrase first introduced by Grandjean in 1981. The process of considering the job of fitting the task to the human describes the science of Human Factors and is also known as Ergonomics. At least from my perspective the terms Human Factors and Ergonomics are interchangeable and for the remainder of this chapter I will use the term Human Factors to avoid any confusion to the reader.

Human Factors generally considers the three major elements of a system to be the Human, Machine(s) and the Environment. The Human-Machine-Environment (HME) approach considers the work and system design as a complex interaction of individual elements of the system and the more importantly the interaction of the elements within the system. For example, if you were to analyze your present situation as you are reading this chapter or your current workplace, and I were to ask you to list a number of components or factors in the HME system, you might begin with a list similar to the entries presented in Table 11-1. Take a moment look around your particular area and expand this list.

Table 11-1: A List of the HME Components

Human	Machine	Environment
• Age	• Lamps	• Temperature
• Sex	• Books – page and font size	• Noise
• Height	• Chairs	• Air quality
• Vision	• Tables	• Lighting
• Reading ability/education	• Pencils/pens	• Humidity

Notice that I have focused on mostly physical elements of all three components, it is important to also consider cognitive function and other characteristics of these elements equally. Looking at this list identify those elements that have some degree of variability for example, the age range may be from 20 to 50+ years, the temperature in a standard classroom can vary from 18 to 25°C (or greater) and you can add other values for many of the items listed. The last part of this exercise is to link elements in one column to elements in the other column(s). For example, vision can be related to the books and the lighting as well as the tables and chairs. This means that to successfully read this material you require adequate lighting, probably a comfortable chair and desk and hopefully large enough print (font size) to be able to read under the circumstances. Therefore to attain an optimal performance from you as a representative of the human element, we need to consider how to design and control the machine and environmental factors in the system.

Hopefully through this simple exercise you will appreciate the following points:

- The human is an important element in the system but brings a great deal of variability to the system.
- Many of the other elements and their associated variability can be designed into the system or alternatively, adjusted or if necessary, designed out of the system.
- Without radical organizational steps, human variability is the most difficult to "control" without measures such as pre-screening or standardization of qualifications.

Proper design for the human will achieve the optimal match between the human and the task(s) which should increase the system productivity and improve overall health and safety. However, designing for the human can only be accomplished if we know the characteristics of the user population. This is true for all designs and all equipment associated with work. In the absence of direct measures of the intended population our alternatives are to find surrogate data sets and plan with that data. This can be problematic in many respects due to the variations in body size that exist globally as well as the variations that exist in different occupational groups. For example, anthropometric characteristics of industrial populations vary greatly based on global region, proportional differences between sexes and mostly likely some individual self-selection based on physical demands of the work. Some of our recent work on human anthropometry related to offshore workers is a classic example of these differences. Through a series of studies we have been able to show that offshore workers in North America are approximately the same stature as their European counterparts, but are on average 14 kilograms heavier (Reilly, Kozey and Brooks 2005). This average increase in body mass will influence maximum carrying capacities and the "fit" of air and sea craft used to transport the workers. While we also have other body dimensions for this population which were reported in the paper there are no other comparable reports for other groups around the world. For instance, the I.M.O. Life Saving Appliance Code prescribes weight and space allocation for lifeboats. The 75 kg weight and 430 mm buttock width is grossly inadequate for North American operators, and using the buttock width is incorrect too. The code should use shoulder width.

SYSTEM THINKING

Vincente (2003) offers a new perspective on the relationship between human factors, design and human or societal needs. He suggested the five basic Human Factor needs in design are physical, psychological, team, organizational and political (Figure 11-1) and he uses the analogy of a ladder with each of these "needs" forming a separate rung on the ladder with the lowest rung being the physical and the highest the political.

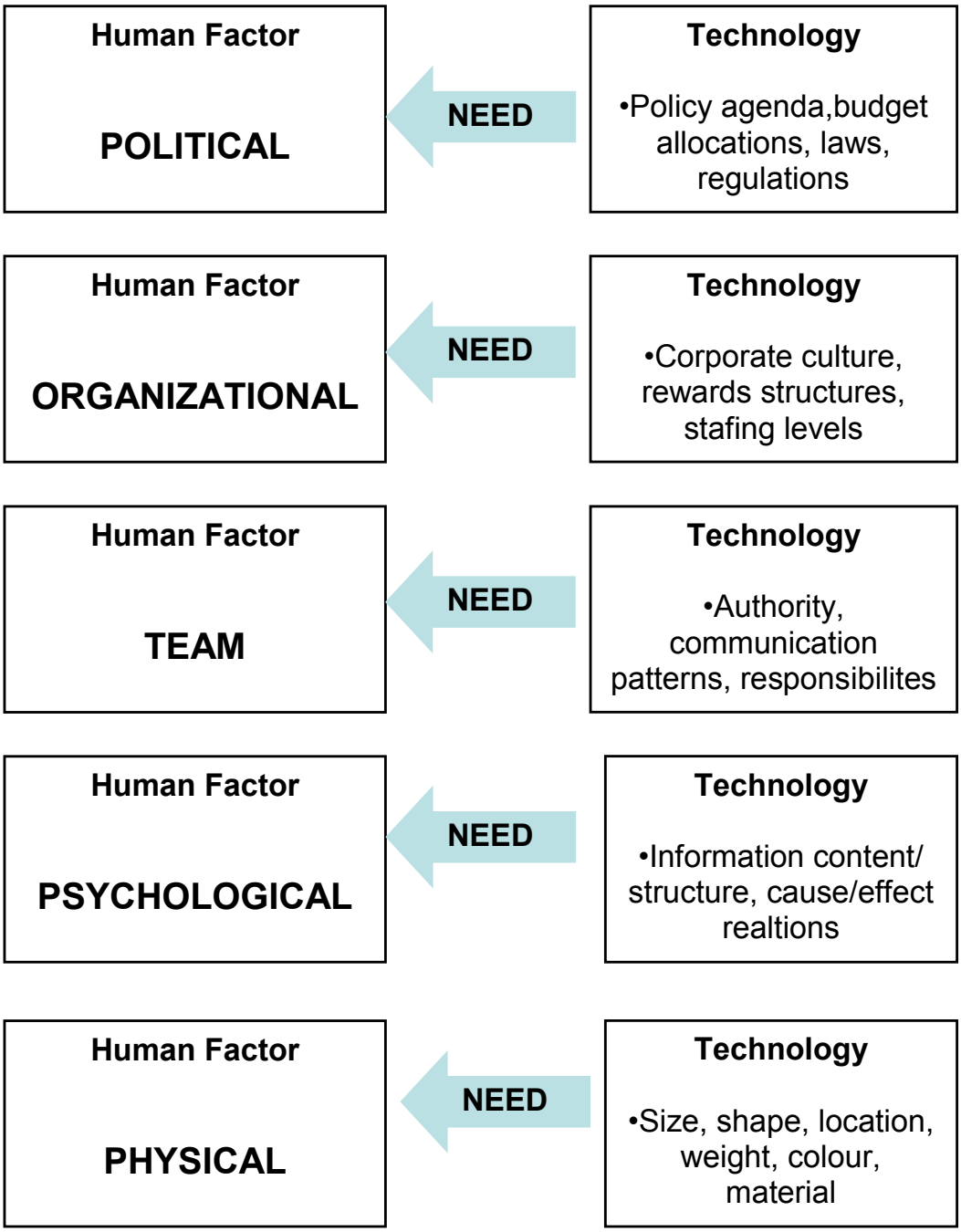

Figure 11-1: A Modification of the Human-Tech Ladder Proposed by Vincente (2003). Design should begin by understanding a human or societal need then tailoring of the specific human factor.

To elaborate on the application of his views I will present some recent research results related to helicopter egress. Then I will discuss how these could impact on design and training issues related to helicopter ditchings. I will focus the applications of these results on the physical and psychology "rungs" and finally the political "rung" of his Human-tech ladder.

Physical (Size, Shape, Location)

Designers of helicopters must consider the human as an integral part of the design process. This then determines where objects can be located, the forces and motions required to operate objects such as handles and other factors related to the ease of use of the handles. This seems simple enough, but it demonstrates some of the complexities involved in design trade-offs. For example, if we consider the reach envelope of the human operator, it is recognized that specific areas within the envelope should be related to the functions of the human while in the aircraft. A prime area of concern is the area immediately in front of the individual and this area should be reserved for frequent, important and often lifesaving tasks. In the case of the pilot and co-pilot this area should be reserved for flight related operations. For passengers and crew in the aft portion of the helicopter, the area immediately in front should be reserved for their important tasks. However, it is likely that the area they may require would be less than that of the pilot and co-pilot. For both groups an emergency jettison handle would be low in terms of frequency of use and therefore can be located away from the prime reach areas. However, the importance of the use of the handle is very high which means that it should be located very close to the prime reach areas, but positioned and designed to prevent unintended activation.

Brooks, Bohemier and Snelling (1994) found that the handles were typically located away from the reach areas immediately in front of the people which would seem appropriate. However, they discovered that the location of the handles varied greatly from one design to the next. This creates difficulties in developing training programs for emergency egress. In essence, training programs had to account for the unique locations of the handles in each helicopter. Furthermore, the many different helicopter configurations and the subsequent errors that were produced in locating the mechanism were complicated by the fact that typically the person would be inverted and underwater. They suggested that release mechanisms should be the same size, shape and position across the helicopters. Later, Brooks and Bohemier (1997) examined the doors, windows, hatches and escape mechanisms on 35 different military and civilian helicopters. They found that there were 23 different types of jettison mechanisms and that the arc of rotation or direction of pull was highly variable. They again highly recommended the development of fewer mechanisms and a standardization of the type, operation and location of these handles.

There are two obvious issues that were highlighted by these papers. The first issue is the development of a standardized handle and jettison mechanism which would reduce the additional training required to find and operate the handles for the different aircraft. The second point is that in the absence of standards for the handle and handle mechanism means there is a requirement for individualized training to both locate and operate each available type. Thus, while freedom is provided at the design phase for the handles and locations, training costs are increased to account for the variability in size, type and location of the handles across the different helicopters, and if aircrew and passengers are flying in different types of helicopters, then there is the problem of learning, unlearning and relearning various schemas to operate the levers when one only has 15 seconds warning of a ditching and only 20 – 30 seconds of breath-holding ability underwater. There is no time for a mistake, if one is made you drown.

Psychological (Information Content, Structure, Cause/Effect Relations)

In Vincente's scheme this means that the type of actions required to manipulate the handle and the subsequent response should be compatible. Again this is a classic Human Factors principle of motion that should be applied to all designs. The motions required to operate the handle should provide feedback (content) to the person indicating that the window has been successfully jettisoned. The motion should be intuitive and require very little information processing. This would imply that the motion should be directed away from the body and that a continuation of the motion would provide feedback that the intent of motion (window or hatch release) has been successful.

Again referring back to the papers of Brooks, Bohemier and Snelling (1994) and Brooks and Bohemier (1997) it is apparent that this principle is not applied to many of the handles and jettison mechanisms. The result (cause/effect) of not applying this basic principle is the occurrence of performance errors of the individual at an instance where time is critical. Brooks and Bohemier (1997) present for example the case where the handle is mounted on fuselage and remains in that position after the window has been released. This provides no feedback to the user regarding whether or not the release was successful which then requires a second action which is to determine if the opening is available for egress. This problem will affect not only the person immediately beside the egress point, but any other crew member who may have to use this point of egress as well.

The **Team** (Authority, communications patterns, responsibilities) and **Organizational** (Culture, rewards structures, staffing levels) rungs of Vincente's ladder are more difficult to describe in terms related to the research to date on helicopter egress. They are however important to many of the factors that may lead up to the reasons for the emergency incident. This includes the normal chain of command (Team) in the helicopter and the climate for safety and preparedness of the company, crew and passengers (Organizational) during such an event. Vincente offers a number of practical examples of these and I would prefer to direct you to those fine examples. I will focus on the final rung being that of policies and regulations.

Political (Policies, Budget Allocation, Regulations)

The final step in the application of human factors can be more broadly interpreted in the context of emergency egress. Hopefully the two examples used for the handle type and location will be seen as simple cases where standardization would be beneficial to the safety of the passengers and crew. I would also like to discuss the issue of training more directly. In many jurisdictions around the world there is a requirement that individuals who fly in a helicopter over water receive helicopter underwater egress training (HUET). This requirement has evolved based on the evidence that training will significantly increase the likelihood of performing a successful egress from a survivable helicopter ditching (Cunningham, W.F., 1978). There is little question that this is a positive step in helicopter/marine safety and has undoubtedly saved many lives. However, what is not clear in this safety movement is the actual content of the HUET programs and thus the content varies from region to region. The variation in content of the HUET programs seems to be influenced to some extent, by the time and cost associated with the training as well as the effect the training may have on the retention of the individuals in the chosen profession. In other words, not everyone enjoys the training and anecdotally it appears that some people opt out of the profession because of the training. However, the actual number of people who do so is difficult to determine.

In order for training to be effective a balance is needed between the fidelity (realism) of the training and the potential adverse affect the training may have on the individual, and others involved. Recently we completed a study involving 191 subjects which compared three different levels of helicopter egress training to see if there was an effect on simulated escapes (Kozey, McCabe and Jenkins, 2006). A balanced, randomized design was used to assign subjects to one of three groups in which each group received a different number of training trials and the fidelity of the groups was altered. The groups were balanced for sex (males and females), and a self reported measure of swimming ability which we referred to as water comfort. Table 11-2 shows the mixture of trials and conditions that the groups underwent.

Table 11-2: Description of the Different Training Conditions for Session I

Group	Conditions	Training Trials	# of Trials
1	1	Immersion, Straight In, No window	1
	2	Immersion, 180° inversion, No window	1
2	1	Immersion, Straight In, No window	1
	2	Immersion, 180° inversion, No window	1
	3	Immersion, 180° inversion, Window in	1
3	1	Immersion, Straight In, No Window	1
	2	Immersion, 180° inversion, No Window	1
	3	Immersion, 180° inversion, Window in	4

As you can see the first two conditions for all groups consisted of making an underwater egress from a Modular Egress Training System (METS) in which there was an opening immediately beside the subjects, but jettisoning a window was not required. Condition 3 for Groups 2 and 3 required the subjects to jettison a standard push-out window prior to making their egress. Group 2 received one trial of this condition and Group 3 received 4 trials of pushing out the window. At the conclusion of the training session 96.8% of the subjects successfully completed Condition 2 (immersion, 180° inversion, No window). The success rate for the first attempt of Condition 3 (immersion, 180° inversion, Window in) was 83.1% and with practice the success rate for the subjects in Group 3 rose to 95.2% for this condition.

Six months after the training session, 153 of the initial 191 returned for a single trial in which the subjects received one trial of condition 3 (immersion, 180° inversion, window in). This would be precisely what they would be confronted with in a helicopter ditching months or years after receiving a HUET course. However there was a wide and systematic change in the percentage of successful subject across the three groups. Table 11-3 shows how significant the addition of the exit makes to the ability to escape from an inverted flooded helicopter six months after training (Session II). Overall 77% of the subjects successful completed the egress. Group 1 which had received no exposure to the push out window and only 2 training trials of the egress had a 54% success rate. Group 2 which received 3 trials in total, one of which involved the push out window had an 81% success rate. Subjects in Group 3 completed 6 training trials in total, four involving the use of a push out window, had a 96% success rate. Clearly there is a major benefit to exposing the subjects to the push out window trials versus trials that do not involve the window and to allow for practice of the task.

Table 11-3: Performance in Session II

Group	Pass	Previous Exit Practice
1	54%	0
2	81%	1
3	96%	4
Total = 153	118 (77%)	

How then does this example relate to policy? It is hoped that these results clearly demonstrate that from a Human Factors point of view, physical fidelity and practice should be included in all training programs.

Hopefully the industries and training organizations around the world will move to create a single international standard that requires the individuals to jettison the appropriate window mechanism, and that training without an exit may well lead the passengers into a false sense of security.

CONCLUSION: TAKE HOME MESSAGE

The purpose of this paper was to demonstrate the importance of human factors research and to show how this knowledge can be used at various organizational levels. The examples used were related to helicopter egress and similar examples exist in a variety of different applications (Vincente, 2003). What is important for you the reader and practitioner to realize is the huge potential you have to contribute to the improved performance of systems and lastly, to understand why it is important to have your input presented early in the design phase of any project.

Shown in Figure 11-2 is an adaptation of a figure from Gawron, Dennison and Biferno (1996) which shows the cost of changes to a system (or product) depending on the status of the product in the development and production phases. If we consider the costs of Human Factors input at the initial conceptual phase to be a value of 1 then we can see how rapidly the costs will rise the later into the production cycle the change is suggested. These costs can reach as high as 1,000 to 10,000 times the initial cost once the product reaches the production stage. To explain this increase in cost Gawron, et al., present a graphic similar to the one shown in Figure 11-3 which relates the development of a product and the point at which costs are "locked in".

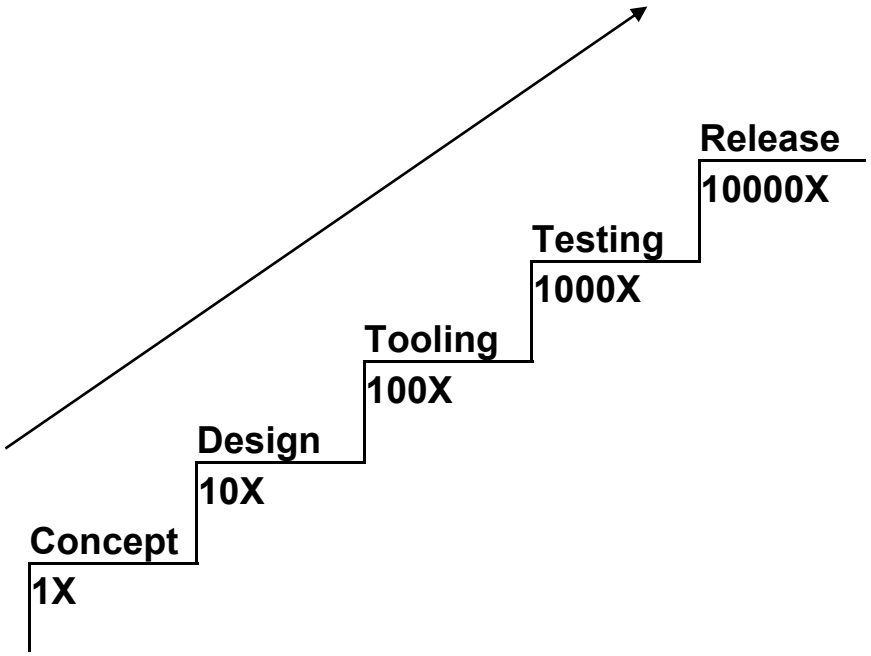

Figure 11-2: The Costs of Design Changes as Proposed by Gawron, et al. (1996).

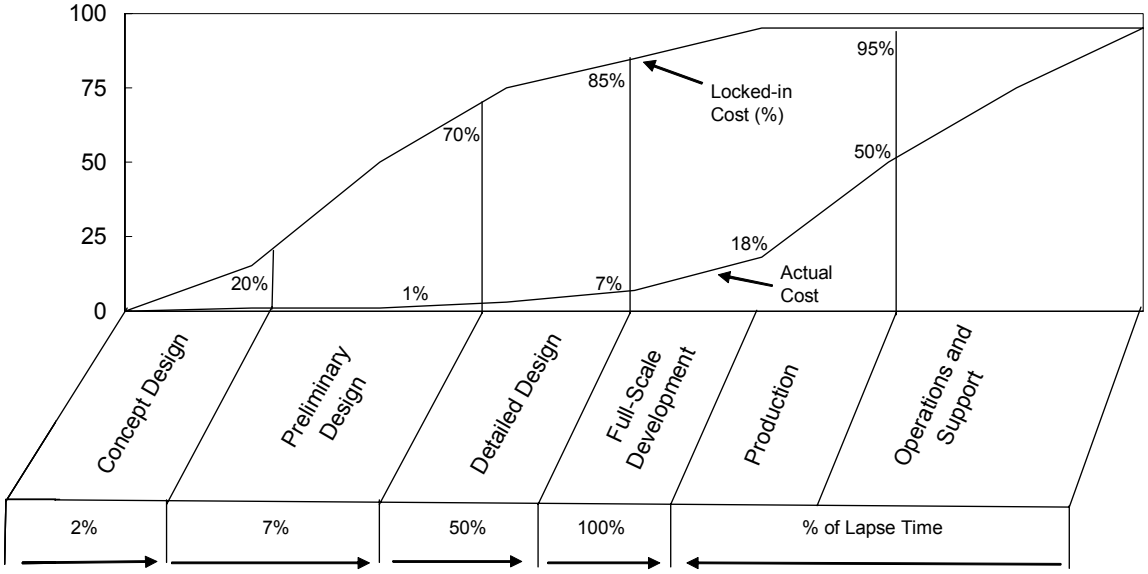

Figure 11-3: Life Cycle Costs as Modified from Gawron, et al. (1996).

As one can easily see early in the production phase much of the costs associated with production become locked in and therefore the costs associated with changes to the product will grow dramatically. While this example applies to the production of a product a similar profile exists for the different levels as shown on Vicente's ladder. Once standards and policies have been established changes to the standard can become quite high and will be resisted by groups already using the existing standard.

So although you may or may not be a Human Factors specialist, you do have expertise in the subject matter in general and your feedback into the design cycle is important. It will most likely be effective if the knowledge and information you have can be present and discussed at the earliest possible phase. This is not always an easy task, but creating a line of communication from you to the design team will in the long run, likely provide important knowledge and impetus for future change and an overall better system and of course save lives.

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