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Prevention Through People: A Strategy for Improving Safety into the Twenty-First Century

Mark VanHaverbeke[1], Randy Gilbert[2] and Patrick DeShon[3]

[1]Commandant (G-MSE-1), Room 1304, 2100 Second St. S.W., Washington, DC
[2]Institute of Safety Management International, 398 E. Eaglewood Ln, MT Jackson, VA
[3]Commandant (G-MSE-1), Room 1304, 2100 Second St. S.W., Washington, DC

Abstract

In this paper we will discuss the U.S. Coast Guard's Prevention Through People program as it relates to ship design, construction and operation. First, we will outline the overall Prevention Through People program (PTP). Second, we will discuss Risk-based assessment concepts, which are the Prevention part of PTP. Third, we will discuss the People part of PTP, giving people the "ability" to be safe.

History

During the 1800's the marine industry saw tremendous advances in wooden ships driven by the wind eventually gave way to steel ships powered by steam boilers and the screw propeller. During this century, significant changes have been made in terms of construction methods, the power plants, and even the screws themselves. Perhaps the greatest evolution has occurred at the end of this century as advances in electronics have produced the gyro compass, satellite communications, RADAR, GPS, weather forecasting, and computer-aided operations on the bridge, in the engine room, and throughout the ship. This appears to have been a century of major safety advances in the construction and outfitting of ships, yet casualties still occur. While we have succeeded in improving our ships from an engineering perspective, we have failed to make similar improvements in the human element aspects of the marine transportation system. Addressing the people side of safety using sound prevention methods is the focus of the U.S. Coast Guard's Prevention Through People (PTP) program.

The PTP Program

PTP recognizes that, while the majority of casualties are caused by the human element, the greatest strides in improving safety may also be made by human intervention at various points in the ship life process. To be most effective, the intervention should be considered as part of a systematic approach. Unfortunately, all too many of our efforts in the past were piecemeal or did not consider the impact of actions on the greater system, resulting in negative impacts unforeseen as part of otherwise positive actions.

Before we proceed further, we need to explain what encompasses the human element. The term goes far beyond what might be inferred by human error to include the accidents, failures, or intentional acts we wish to prevent as the end point; as well as the organizational and individual acts or omissions which provide the set of conditions necessary to reach the undesired end point. PTP is a systematic approach to safety, recognizing the impacts of one part of the system on another.

PTP Foundation

PTP involves more than preventing accidents by seafarers and shoreside facility workers. PTP is not just a Coast Guard effort, it involves every member of the maritime industry: designers, builders, classification societies, crews, management, mariner organizations, port authorities and government agencies. We should all share responsibility and all share a common goal: to reduce casualties and pollution. We owe it to the public and it's just plain good business.

To address improving safety through prevention, a Coast Guard quality action team developed a systematic approach to the human element in managing safety performance. The approach creates a new safety culture which includes four key pillars, all based on a solid foundation of standards. The pillars, as listed in figure 1, are: 1) management; 2) work environment; 3) behavior; and 4) technology.

A solid, level foundation requires well-conceived and fully-implemented international regulations, classification rules, and industry standards, as well as support from non-governmental organizations and their representatives, policy making industry groups, and insurers.

The International Maritime Organization (IMO) has made significant strides in recent years towards strengthening the foundation.

This strengthening has come about by encouraging the continuous growth of safety management skills in the maritime industry through the International Safety Management (ISM) Code and the International Convention on Standards for Training, Certification and Watchkeeping for seafarers (STCW).

These standards and regulations provide the solid foundation upon which everything else is built. When all who make up the foundation act in concert, operators have a base upon which better operators can compete fairly, and marginal operators are forced to either improve or be driven out of business.

Management Pillar

The management pillar embodies the corporate culture that promotes safe and environmentally sound operations. The corporate culture is seen in a company's goals of no oil or chemical spills and injury-free operations, and also in its expectation of full compliance with all safety and environmental standards.

Work environment Pillar

The work environment pillar refers to those external factors which affect people's judgment, efficiency, and effectiveness. This can include the ship's physical layout, man/machine interfaces, waterway/port conditions, congestion, weather, time of day and personal interactions.

Behavior Pillar

Those personal factors which affect an individual's performance comprise the behavior pillar. Examples include personal leadership, aptitude, health, values, work load, stress, fatigue, training, attitude, physical capability, experience and prejudices.

Technology Pillar

The fourth pillar involves the introduction of technology into the work environment. It includes research, development, systems, design, materials, equipment, and information management. Technology must be designed for compatibility within human capabilities and limitations.

The four pillars - (1) management, (2) work environment, (3) behavior, and (4) technology - must be built on a solid foundation and kept in balance, or the structure could fail. For example, the application of new technology requires standards to ensure that the application be done safely and good management to ensure that the crew is properly trained.

This systematic approach can only be undertaken by a joint effort of the elements involved in marine transportation. The government cannot mandate this people-focused approach and industry cannot undertake it without the support of government and standards-setting bodies. However, by working together, we can all move towards a common goal of safe and profitable marine transportation.

PTP involves a "cradle-to-grave" system safety concept. An example to consider, in which we all could have done better from the beginning, may be found in the ATIGUN PASS class of 165,000 DWT tankers operating in the Trans-Alaska Pipeline Service trade. Almost from the beginning of their service lives, the tankers were plagued by structural problems, including fracturing of longitudinals and eroding of master butt welds, which were brought on by detail design and construction (The role of "constructability" will be discussed later in this paper). A total of six vessels were involved, of which, four were controlled by two companies.

Where do we go from here? We're engineers, and the more egotistical among us would like to think that we can engineer out the possibility of failure. Even some non-engineers would like to think they can eliminate the impact of marine casualties through engineering solutions. We can't. If the EXXON VALDEZ had gone aground with a double hull it is predicted that we still would have had the largest spill this country has ever seen, and the subsequent salvage effort would have been significantly more complex. It is time for us as engineers to recognize that humans design, construct, operate, maintain, inspect, and repair ships and that we are not doing our job right if we don't address these human element issues from the beginning. In many respects, we engineers are the primary structure for Prevention Through People.

Risk is the Prevention Part of PTP

In this discussion of Prevention Through People and introduction of the concepts, it is important to keep foremost the objective of the program. It is simple and easily recalled from the program name. The keyword is prevention. Prevention of what? As stated earlier, the shared goal is to reduce (or prevent) casualties and pollution. Some may point out that absolute prevention is impossible. But according to Deming's quality management principles, which taught constancy of purpose, we learn that a vision must be something which is not quite attainable; it always inspires further improvement. That is why our goal is the prevention of casualties and pollution.

Traditional prevention of casualties and pollution has taken the form of response to casualties or major incidents. This "learning from our mistakes" approach has led us to many symptomatic solutions. Often the root cause was never actually determined and many solutions were aimed primarily at the effects. Again the double hull tanker solution serves as a good example. This responsive posture had probably its greatest weakness in that the marine community waited in anticipation for the next disaster which would show us our faults. We and the environment were then forced to deal with the damage left in the wake of our education. This was not truly prevention but merely reaction.

What is needed is a framework by which to break apart the methodologies dealing with risk. This framework will provide a means of comparing methods and assessing the most appropriate for application to a given system. Risk is only prevented after preceding stages have been addressed. Stages for the prevention are as follows in each of the following stages:

- Identified/perceived,
- Measured,
- Predicted,
- Prevented.

As technology has advanced and the size, speed, cargo capacity and complexity of the vessels have increased, so have the consequences of failure. As the consequences grow, a point is reached where we are not willing to wait for them to become reality. If we are to avoid the unacceptable then we are forced to anticipate the undesired events before they happen. These concepts began to be perceived in early aircraft applications and were fully realized during the development of the space program by NASA after its creation in 1958.

Risk as a Potential

If we look at undesired events from a Newtonian mechanics perspective, Newton's laws of energy will tell us that an object may possess potential energy and kinetic energy, and that potential energy can be converted to kinetic energy when the proper conditions exist. Similarly, every system possesses a potential for an undesired event to occur. Under certain unsafe conditions the introduction of an undesired act can convert that potential into kinetic energy which will produce an undesired event. The potential for this undesired event has been termed "risk." Preclusion of those hazardous conditions and undesired acts which could allow risk to become tragedy is truly the meaning of prevention.

People design, people construct, people operate, people maintain, people inspect and people repair. People are the cognitive part of every process. People, through their actions, choose to create the conditions or perform the undesirable acts that allow the potential for undesired events to be converted to actual undesired events. Risk-based methodologies recognize this relationship between people and potential and set the structure through which these hazardous conditions and acts may be identified and predicted. We must anticipate undesirable conditions and acts so we can prevent their combination and resulting consequences. Otherwise we will continue to react to casualties instead of learning to prevent them.

The Value of Risk Assessment

The tools of prediction already exist, have been used for years and have been extensively developed by mathematicians and engineers. What is now needed is a framework within which these tools can be applied to risk. This framework is risk assessment. Risk assessment is not something completely new and often seems like common sense but it is significant in its contribution to safety.

Edison's development of the first commercially practical incandescent lamp (1879) and his design for a complete electrical distribution system for lighting and power, culminated in the installation (1881–82) of the world's first central electric-light power plant in New York City[1]. This was more than 250 years after William Gilbert developed his first theories regarding electricity. Many inventors prior to Edison harnessed electricity, and incandescence was no secret, but Edison made it work in a practical way that changed our world. Just as Edison's work gave us the practical use of the concepts in electricity, so risk assessment is the practical application of the tools which have already been developed. Risk assessment provides the means for application of these prediction tools enabling us to prevent catastrophic consequences and to change our world.

Goals of the Marine System

Now some may question our statement that everyone has the goal of preventing casualties and pollution. True, the ultimate goal of the industry is to succeed economically, as any business must to survive. The ultimate goal of the government is the protection of its citizens. Citizens may be either consumers or producers and each has different primary concerns. Sometimes these concerns can be in conflict. What Prevention Through People points out is that each group's ultimate goals may be met through shared concerns regarding the prevention of casualties and pollution.

Obviously a marine system with no ships or activity would be very safe; however, it would not be a system anymore

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because it would cease to perform its objective. In this scenario the cost of safety, in terms of dollars, is too high for the producer. At the other end of the spectrum high levels of risk force the shutdown of the system to protect its consumers from the associated hazards. Again the cost is too high, but for risk the costs are defined in terms of citizens' lives or environmental resources. The goal of government is to find a balance between the costs of safety and the costs of risk which is acceptable to both the producer and the consumer, as shown in fig. 2. In order to support performance of objectives, both are willing to accept a certain level of risk.

Elements of Risk

Risk is a consideration in every decision made regardless of the role of the person making the decision. Every person in the marine system considers risk in some way. This consideration may be conscious or unconscious, formal or informal. Unconscious consideration takes place when your brain compares two actions and weighs the likelihood of one or the other resulting in harm. Simultaneously the brain weighs the undesired consequences associated with each action. These two elements are then combined to influence how the brain will make a choice between the two actions. This whole process may take place in less than a second and the individual may not even be aware that it has taken place, but the fact still remains that a decision has been made and that the brain has made that decision based on information defining these two elements.

Prioritization of Risk

The brain compares these risk levels subjectively, while risk assessment provides the tools for engineers to measure the level of risk. If we hope to exercise control over a process, we must be able to measure it and gain feedback. Otherwise we will have no reference to ensure that our controls are effective. The criteria by which these factors are measured varies with the application.

Consequences may be defined in dollar amounts, severity of injury, number of deaths, extent of pollution or in terms of any other undesirable event. Likelihood may be assessed in terms of frequency of occurrence or probability. If events are then plotted on a graph according their values, lines of equal risk value will emerge as shown in fig. 3.

By analyzing these lines of equal risk we can determine zones of acceptability or zones of comparable risk. The goal of risk management is to move the measured events down to regions of greater acceptability as shown in fig. 4. If we superimpose a grid over these zones, as in fig. 5, we can target regions of comparable risk and will begin to see where one of the most common risk tools comes from.

The risk assessment matrix is probably the most common means of targeting items for risk reduction. Used by both engineers and managers, the matrix simplifies classification of comparison and provides a quick means of prioritizing the events. By establishing a simple frame of reference, consequence and likelihood may be easily ranked in comparison.

Although there are common practices for defining the categories, the reference frame may be defined in any manner which will best assist in analyzing the risk scenarios. A typical set of likelihood and severity categories is shown in fig. 6 and fig. 7.

These categories when plotted against each other provide the matrix by which prioritizations may be made (fig. 8).

Once prioritized, these risks may be dealt with using risk management concepts to reduce unacceptable and undesirable risks to more acceptable levels. There are other means of quantifying the risk, but this method is probably the simplest and the most easily explained. Further explanation of this and other popular analysis techniques is presented in Stephenson (1991).

Reliability and System Modeling

Reliability, one of the recently developed engineering sciences focuses primarily on the determination and prediction of the likelihood side of the risk equation. At its most basic level, reliability assumes that a system's failure rate may be approximated by modeling the system and predicting the failure based on the abstracted variables. This failure rate may then be used to assess the probability of failure under given conditions. Combined with the consequence, these probabilities can provide highly accurate predictions of risk level.

The key to this approach is the model itself. In modeling the system, the engineer introduces uncertainty both non-cognitively and cognitively. Either choosing to abstract or not to abstract a variable may add uncertainty to the model. Abstracted variables may introduce uncertainty through physical randomness, statistical uncertainty or simplified assumptions. Non-abstracted variables may actually have more significance than anticipated or may not be reasonably modeled due to complexity, ambiguity or vagueness. Also, insufficient knowledge or training may prevent the engineer from recognizing other significant parameters.

The level of uncertainty present in a model will determine the effectiveness or applicability of the analysis. This uncertainty factor can be used when evaluating a method or model to make quality determinations. This modeling process is at the heart of reliability engineering and is well illustrated by fig. 9, borrowed from Ayyub and Gupta (1995). Ayyub covers cognitive and non-cognitive uncertainty as well as the effects of ambiguity and vagueness in more detail.

Risk Management

Assuming a proper method has been chosen, the level of risk has been determined and priorities have been assigned, it is now time to begin to deal systematically with those risks. This is where risk management is introduced. Risk management is essentially the evaluation of assessed risks to establish the most effective and feasible controls. After prioritization of risks has been completed it is essential to determine how they will be dealt with. This is done systematically using the Safety Precedence Sequence. The following Safety Precedence Sequence is used to eliminate or control identified hazards:

Designing for the minimum hazard is the risk manager's first and most effective way to lower the risk. By removing the hazard or substituting a lesser hazard the consequences of an undesired event are greatly reduced. Many recent fire protection standards have followed this premise by placing limits on allowable fire load for certain vessels. By reducing the amount of fuel source present both the consequence and the likelihood of a fire are reduced.

If it is unfeasible to design out the hazard the engineer must predict likely failure events and devise means of countering them. The safety valve or the overspeed shutdown are good examples of this. Again this can reduce the consequence or likelihood of an undesirable event.

After we have done all we can to correct the physical system itself we must ensure that the operator as part of the system can predict or react to any potential undesirable events. Warning devices can be audible, visual, or any other type of stimulus which can be interpreted by the human as a warning signal. Warning devices will call attention to the hazard and notify the human to take action. The goal is to ensure that the operator is able to avoid the undesired consequences.

Care should be taken so as not to mistake a monitoring device for a warning device. Monitoring devices provide information on operating conditions and may warn the operator of deteriorating conditions, but do not constitute a warning device as the human has actually performed the warning instead of the device. A pressure gauge is not a warning device. A siren that activates when the pressure gauge reaches a certain value is a warning device.

The last step in reducing the risk is to ensure that the human has the knowledge and ability to interact safely with the hazard. Operators are taught procedures to safely work with the hazard, avoid interaction with the hazard or to neutralize the hazard when necessary. Also, designers ensure that the operator possesses the capabilities to safely operate the system.

Once the Safety Precedence Sequence has been reasonably exercised, the remaining risk should be below the acceptable level. If the risk is still unacceptable, the system is not feasible and must be abandoned.

The People Part of PTP, Giving People the Ability to be Safe

Another way of stating the focus of the Coast Guard's Prevention Through People Program is fostering a safer operation by preventing accidents through giving people the ability to be safe. Its the quality of being able to do the right thing. Deming said he believed that 85% of all problems are the fault of systems which govern or manage people (management), not the fault of the people themselves. He indicated that working towards understanding and fixing the system gives people the ability to do their jobs correctly. This fosters a cooperative attitude allowing people to want to do their jobs correctly. The marine transportation system has similar problems which are caused by people being restrained in their ability to always do the right things right. Thus we will focus on applying prevention techniques to proactively ensure that people are given the ability to do what is necessary to perform their tasks correctly without providing the actions that convert a potential event into an actual event.

There are five aspects of ship structures we address and relate to the Prevention Through People program:

- Designability,
- Constructability,
- Operability,
- Maintainability,
- Inspectability.

Each of these five aspects are important in all aspects of marine operations as shown by fig. 10, but we will limit ourselves to only dealing with ship structures.

Designability

PTP principles are best applied at the very beginning of the life-cycle of a vessel. The strongest preventative measures and the largest savings from "doing it right the first time" can be achieved at this point. At the very earliest stages of the concept there should be an ability for the human designer to do it right. Doing it right is a lot easier to say than to do. Trying to define how to "do it right" is daunting; it means too many things to too many people. However, if we don't take the first step, we all know that there will not be a second or a third.

The Ability to "Do it Right"

Starting with a problem solving tool called the Cause & Effect Diagram (fishbone diagram) we've mapped out what is needed to design it right. This tool is successfully used often in the Coast Guard. If designability is what we would like to achieve, then what major categories of causes would we need to consider? We've come up with the six categories listed in fig. 11.

The Designer's Working Environment

The Work Environment causal category covers the basics of Maslow's Hierarchy of Needs. This is a very important area which is often overlooked or given a very low priority in a design office. Recalling Maslow's triangular illustration (fig. 12), physiological and physical needs (health and safety) were at the bottom. In a design office, stress can become a killer if not kept under control. There is much written about how to reduce stress, so we recommend learning good methods and practicing them.

Psychological needs (belonging, esteem, and self-esteem) are in the middle of Maslow's triangle. The manager of a design office needs only to read Scott Adam's Dilbert cartoons to realize what he is up against in creating a conducive environment in today's information age. Many good books contain sound advice and a good manager will concentrate a lot of effort in meeting peoples' needs in this area. There is plenty of merit to the statement "If you take care of your people (i.e. create a conducive environment for working) they will take care of your customers."

The need for Self-Actualization (doing it right because it's the right thing to do) is at the top of Maslow's triangle. This highly creative and innovative area is where every designer should be. There is strong economic incentive for a manager to foster this optimum environment. It is widely known that an innovative person will consider a high number of variables at once. Therefore, the optimum working environment will provide the highest probability of considering all of the design aspects of constructability, operability, maintainability, and inspectability.

The Designer (People)

The People causal category covers having people with the right education, training, and competence. Since our topic is ship structures, the right level of knowledge, skill, and proficiency in designing structures that are people-friendly is very important. It is becoming increasingly necessary for designers to be familiar with human factors engineering standards. The authors have found Bea's report SSC-378 entitled "The Role of Human Error in Design, Construction, and Reliability of Marine Structures," to be a valuable resource. As a minimum, a designer must be conversant with the ASTM F1166-88 standard for "Human Engineering Design for Marine Systems, Equipment, and Facilities." Since the highest probability of designing it right will come from those who are at the highest level of knowledge, skill and proficiency, it is paramount for a manager to help each person to attain that high level.

One key success factor in this category is having practical hands-on experience. There are some naval architecture educational institutions, Webb Institute being one of them, which require each student to get some experience in a shipyard. It is good to learn firsthand which structural design features are good (and bad) by observing and experiencing these features; it adds a large amount of rationality and judgment to designability.

The Designer's Policies

The Policy causal category covers the wide sweeping area of design standards, rules, requirements, regulations, guidance, etc. It is an area in which designers may live in frustration because they have so little control over the policies promulgated by other organizations and may not be able to change the policies that hinder the ability to "design it right." Admittedly, many of the design rules are old and may not allow for the important people-friendly aspects of design. In the Coast Guard's PTP program, there is an objective for training regulatory project officers and policy makers about the human element. It would behoove designers to work with the Coast Guard, classification societies, and other appropriate standards development organizations, to assist with identifying areas in policies which need to be changed. If there are policies which are promulgated by departments outside of the design department (i.e. contracting, procurement, legal, etc.) that hinder safe designs, then the design manager should do whatever is necessary to get those policies modified.

The Designer's Procedures

The Procedures causal category deals with the management procedures and processes that a designer must work within. If one looks at the process of designing ships as a general system, there are certain aspects of the process, such as regulatory plan approval, which are outside the control of the designer. In the Coast Guard's PTP strategic plan, under the section of Cooperate More, there are several activities which are aimed at working closely with the industry to improve safety. Since one of the guiding principles is to seek non-regulatory solutions for improvement, regulatory reform and other needed changes in the overall regulatory system should come through partnerships.

The Designer's Man/Machine Correlation

Man/machine correlation, as we've defined it, is directly related to Human Factors Engineering. If the correlation is unity, then the person will always operate the machine correctly. If the correlation is nil, then the machine is always operated incorrectly. For a designer, himself this category may seem somewhat benign. However, if the computer (machine) a designer uses, is difficult to use and causes mistakes, there can be severe consequences. Many of the problems discovered in the course of a stability review at the USCG Marine Safety Center are due to the designer's improper use of software. Some of the cause of this problem is the human interface of the software. Therefore, it is important for a designer to select software that is well documented and creates the highest man/machine correlation so a person will always use the machine (the computer) correctly.

The Designer's Job/Personality Correlation

Although the Job/Personality Correlation casual category might be placed under People, we've listed it separately in order to draw attention to its significance. Personality typing has been a practice performed by psychologists for many years. The most widely known of these tests is the Myers-Briggs. There are several other testing methods, each with pros and cons and different intended purposes. What is of significance is that certain jobs require a certain personality type in order for them to be done well. Many companies are finding that hiring people into jobs that they are well suited for reduces on-the-job stress and can improve performance significantly. It stands to reason that if a designer is performing at a high level, then there is a far greater chance of "designing it right" all of the time.

Constructability

The Constructability of a vessel, (building it right) is extremely people intensive. Even with modern facilities, there is a large percentage of the ship building process that involves people. The efficiency of a shipyard is commonly measured in employee hours per compensated gross ton (hours/CGT). The estimated average for U.S. shipyards is between 150-200 hours/CGT. Averages for world class shipyards, which have focused on improving processes and procedures, are less than 20 hours/CGT[2].

Since a large portion of the shipbuilding process is taken up in building the structural part of the ship, improving the efficiency of shipyards will reduce the number of people involved. It is therefore even more important that we seek ways to give all of the people involved in constructing ships the ability to do it right. The same causal categories for designability apply to constructability. We will detail a few of the more important ones to further illustrate the PTP focus.

The Builder's Working Environment

The typical working environment experienced by shipyard workers during the building of the ship's structure is physically harsh. It is often out in the weather where it can be extremely hot (or cold), in smoky compartments, and requires bending or contortionist positions. There are also many dangers and chances for injury in using current procedures. Additionally, because of adverse labor-management relations, there is poor psychological concern for feelings of belonging or esteem. Because of the inability to progress above the bottom of Maslow's Hierarchy of Needs, there is little chance of these workers rising to the level of self actualization, and therefore, there is a low probability of involving these people in preventing accidents.

To turn this poor situation around, shipyard managers will need to do some of the same things that the world class shipyards have already done. The working environment in those shipyards is out of the weather, has plenty of ventilation which keeps the smoke cleared, and the work is organized so that it is not physically harmful. Additionally, most of the workers are involved in work teams in which improvement ideas are welcomed, implemented and rewarded.

The Builder (People)

Ensuring that shipyard workers have the right education, training, and competence is a responsibility that is not clearly delineated at most shipyards. There are a myriad of jobs and the overall safety of a ship depends on them being done well.

An example of this being particularly important is the job of welding. Inspectors and surveyors need to continuously verify that welders have the right certifications and much time is spent inspecting welds and then requiring poor welds to be gouged and re-welded. However, inspectors can't find all weld problems and inspection rarely increases the quality of welds. Therefore, each shipyard should have a good program of ensuring that welders have the right skills and are properly trained and tested for the job they need to perform. Adequate training enables welders to perform at maximum efficiency, quickly and safely.

The Builder's Procedures

Being able to build something in the right sequence is not only logical, it is also more profitable and much safer! The best procedures begin by analyzing each task that a person is required to perform, then creating the process which allows each worker to perform within his or her capabilities and limitations. Requiring a person to weld something that is out of easy reach or line of sight is planning for an accident or poor weld. What are you asking your workers to do? Involving your workers in the planning stage of construction enables them to become valuable partners in the efficient construction of a ship. World class shipyards design their procedures with their workers so that each worker is responsible for the quality of their own work.

2 Numbers presented by A&P Appledore, 7 July 1995, at the MARAD sponsored Conference on Shipbuilding Competitiveness

Quality is not the responsibility of the inspectors and foremen. Quality is built in by the workers.

The Builder's Man/Machine Correlation

Each machine, tool, piece of equipment, etc. that a shipyard worker uses should be designed so that the worker is always going to operate or use it correctly. The machine needs to be completely compatible with the worker's basic human behavioral requirements of spatial relationships, operational expectations, and cultural expectations. For example, a few expectations are: instructions are read from top to bottom and left to right, valves turn counterclockwise to open and clockwise to close, red means warning or stop and green means go, and T-bar handle controls are pulled while mushroom controls are pushed.

Operability

Operability as it applies to the structural part of a ship entails giving the Master and his crew the ability to load, carry and off-load cargo without endangering the structural integrity of the ship. Operability encompasses anything which prevents damage to the ship, including proper operating procedures to deal with rough weather, navigating to prevent collisions and allisions, staying within bending stress limits, and moving cargo without damaging the structure. We will illustrate a few more causal categories for operability.

The Operator's Procedures

The requirements of the new International Safety Management (ISM) Code generally cover this area. It has become obvious that well written safety procedures which document what a person is accountable for doing is very important. The ISM Code also requires documentation showing that each procedure has been followed. It is recommended that all safety procedures be developed with the help of the ships' officers and crew so that the procedures are relevant and valid.

Maintainability

We have listed maintainability separately from operability because it involves different people, different policies, different procedures, etc. For the purposes of this paper, maintainability involves giving people the ability to repair, clean and maintain the structural part of a ship. This includes ensuring coatings are kept intact, repairs are timely, there is proper maintenance and cleaning of tanks and equipment, etc. Most importantly, maintainability should include a preventive maintenance system which maintains the structural integrity of the ship. Planned, or preventive, maintenance always costs less than unexpected repairs. Planning for maintenance is planning for safety.

Inspectability

The inspectability as it relates to ship structures involves giving inspectors the ability to actually see the ship's structure whenever needed. This means all tanks can be made easy to flush or clean. Inspectability means having easy and safe access to all areas of the structure of the ship, which is provided for in the design phase. When accessibility is also included in the operability, you don't have to shut the ship down to perform inspections.

Conclusion

Given the complexity of human interface in ship design and throughout the life cycle, it is obvious that a systematic approach is needed to address safety throughout. The Prevention Through People program is a comprehensive, systematic approach to assisting people to become the prevention. Only by shifting the safety focus from response to prevention can risks truly be managed. The success depends on all in the marine industry; government, management and labor.

Risk analysis and risk management can be utilized to build prevention into the system. Systematic management of risks requires consistent metrics to improve the reliability of its prediction tools. The causal categories presented earlier, in the fishbone diagram (fig. 11), suggest a framework for metric collection. Properly utilized, the tools of risk will help to identify areas where the greatest opportunities for safety improvement exist. But we must apply PTP to all aspects of the marine transportation system, in the vessel life from the drawing board to the breakers, and from the deck plates to the boardroom, to address the human element in maritime safety.

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Acknowledgements

Special thanks is given to Dr. Bilal Ayyub for his contributions to this paper in the area of modeling uncertainty and throughout the discussion of risk.

SAFE & PROFITABLE OPERATIONS REQUIRE CONSTANT AND BALANCED INTERACTION BETWEEN EACH COMPONENT TO MANAGE RISK

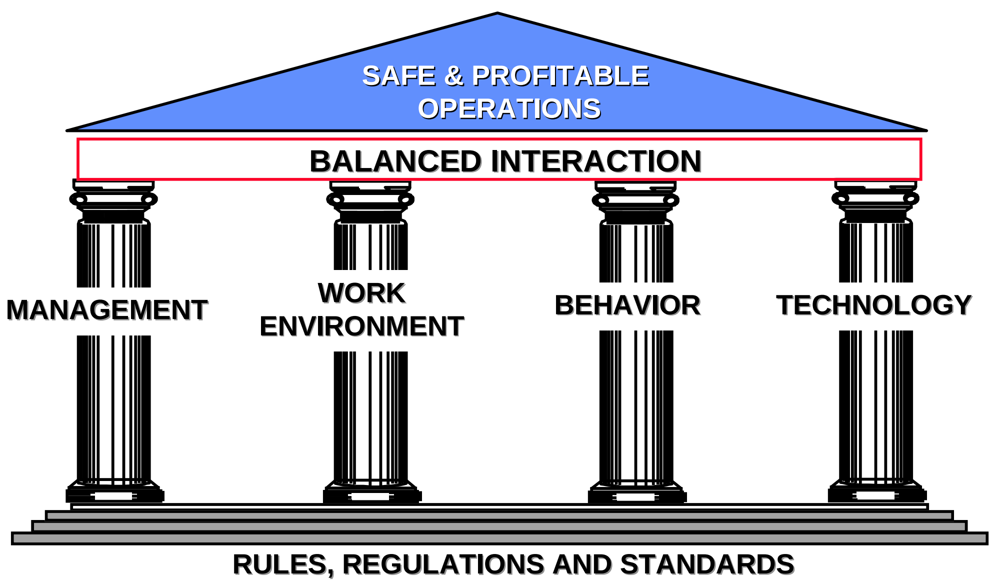

Figure 1
Foundational Pillars of PTP

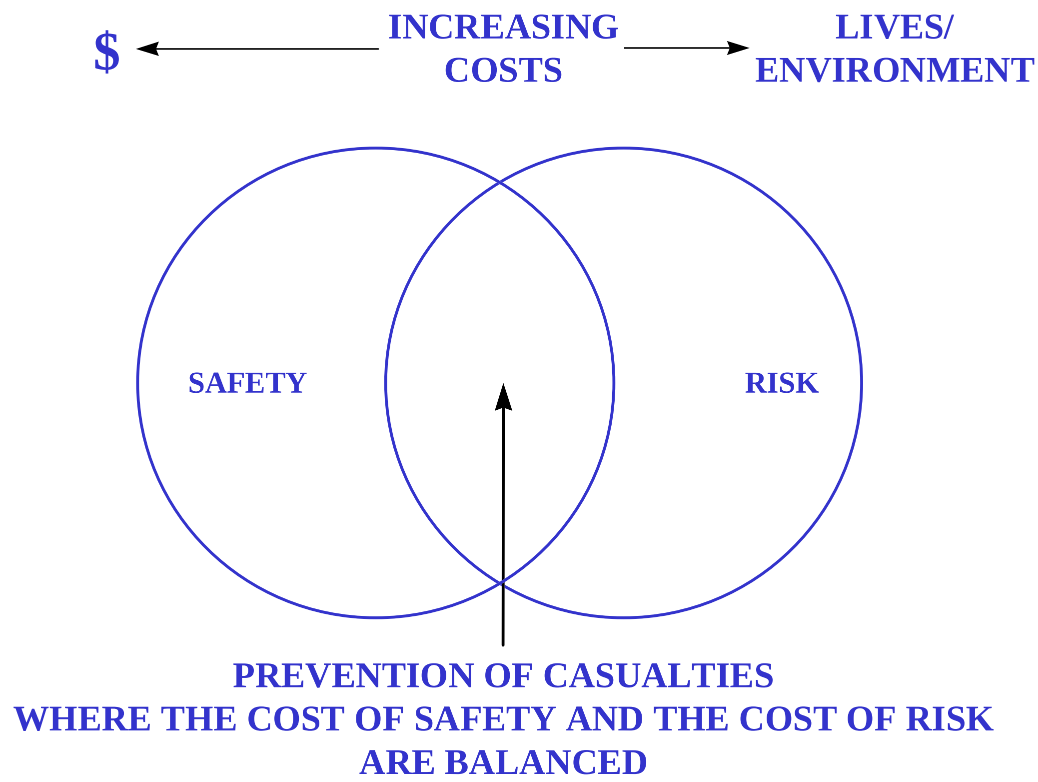

Figure 2
Interrelationship of Risk and Safety

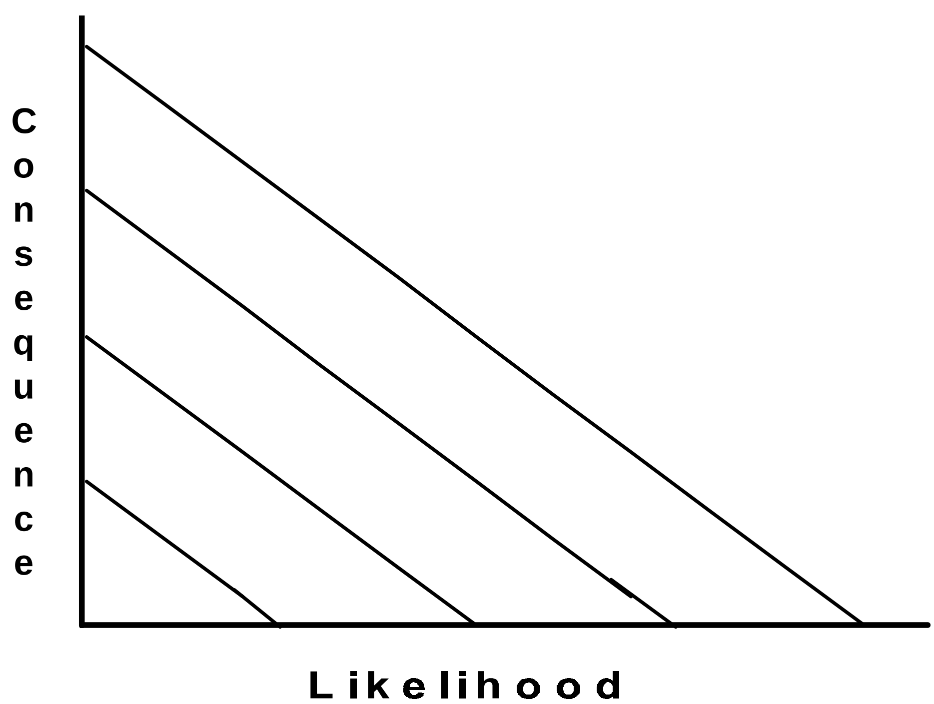

Figure 3
Risk Acceptability Zones

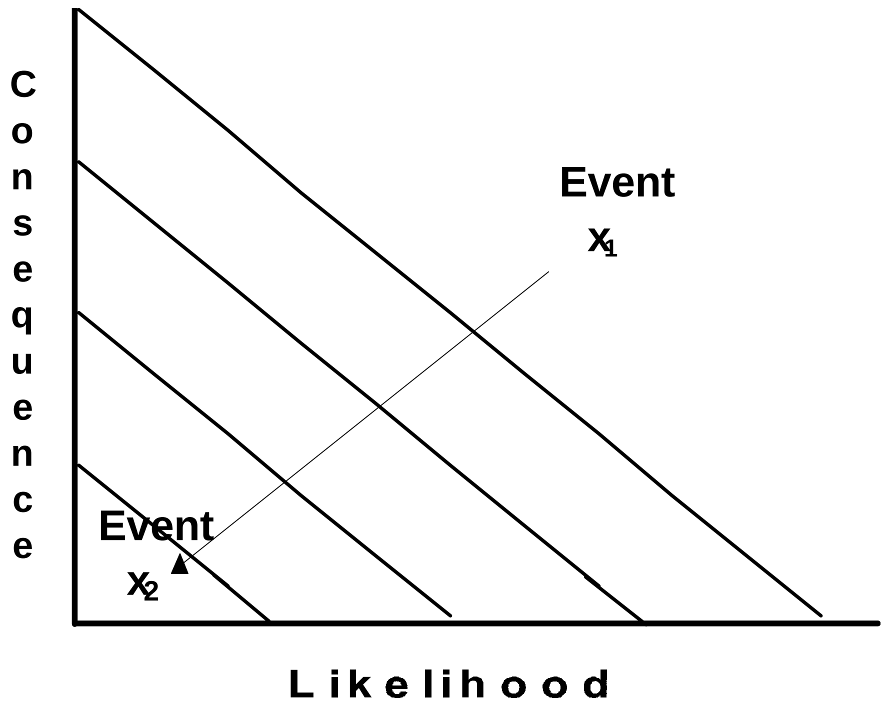

Figure 4
Risk Level Reduction of Hazardous Events

Consequence

	1	1	1	1	1	1	1	1
2		1	1	1	1	1	1	1
2	2		1	1	1	1	1	1
3	2	2		1	1	1	1	1
3	3	2	2		1	1	1	1
	3	3	2	2		1	1	1
4		3	3	2	2		1	1
4	4		3	3	2	2		1
5	4	4		3	3	2	2	
5	5	4	4		3	3	2	2

Likelihood

Figure 5
Risk Matrix Superimposed on Risk Equivalency Zones

Category	Description	Characterization
I	Frequent	Likely to Occur Several Times a Year
II	Probable	Will Occur Several Times in Life of System
III	Occasional	Will Occur Some Time in Life of Process
IV	Remote	Unlikely to Occur in Life of Process

Figure 6
Likelihood Categories

Category	Significance	Characterization
A	Catastrophic	Death or System Loss
B	Critical	Severe Injury of Occupational Illness or Severe System Damage
C	Marginal	Minor Injury or Illness or System Damage
D	Negligible	Less than Minor Injury or Illness or Minor System Damage

Figure 7
Severity (Consequence) Categories

Severity Category	Likelihood Categories			
	IV	III	II	I
A	3	2	1	1
B	4	3	2	1
C	4	4	3	2
D	4	4	4	3
E	4	4	4	4

Risk Categories:
1 - Unacceptable
2 - Undesirable
3 - Acceptable with Review
4 - Acceptable

Figure 8
Typical Risk Matrix

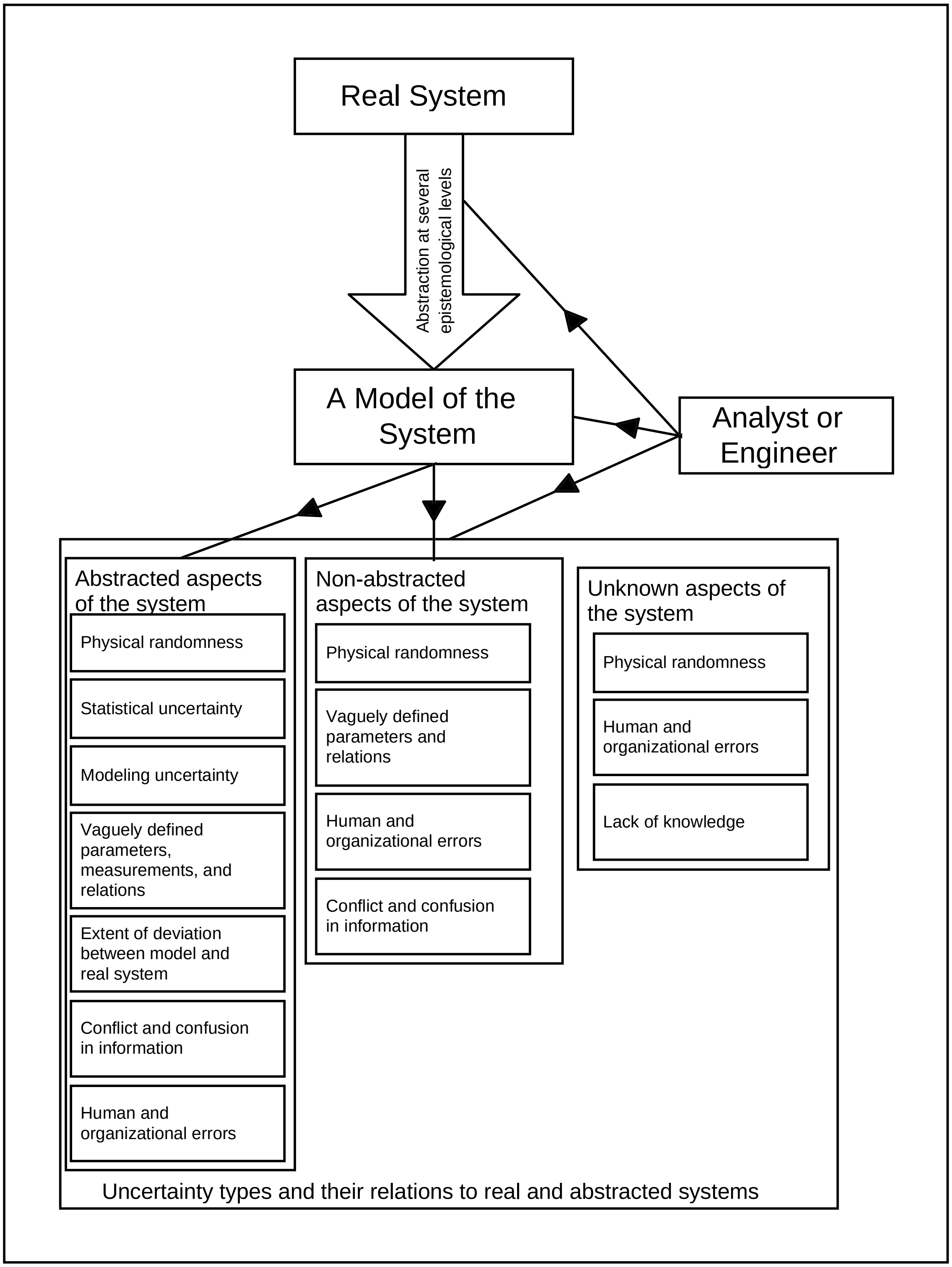

Figure 9
Uncertainty Types for Engineering Systems (from Ayyub, 1994)

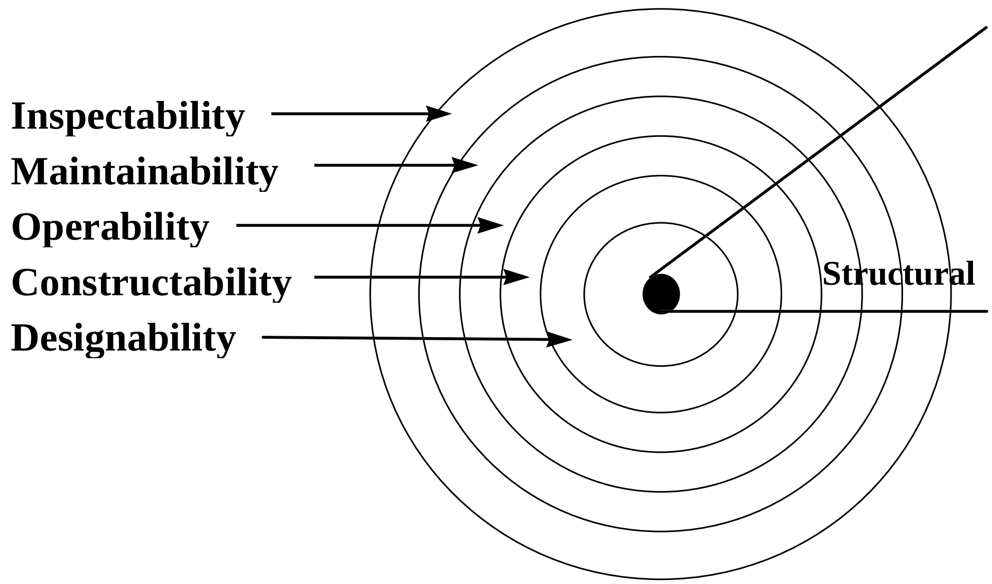

Figure 10
Aspects of Ship Structures

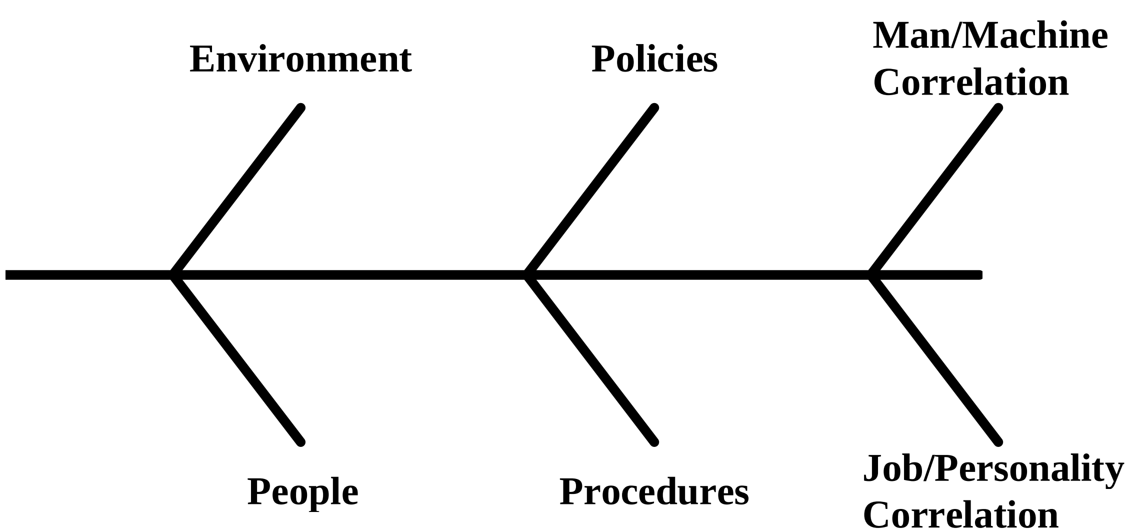

Figure 11
Fishbone Diagram of Causes Effecting Designability

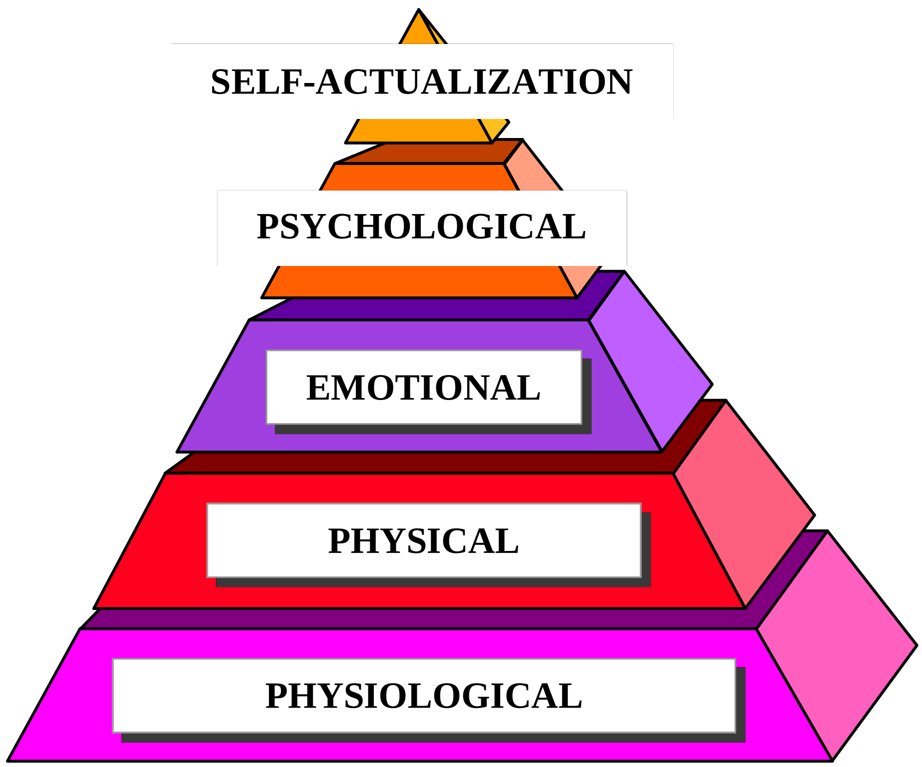

Figure 12
Maslow's Hierarchy of Needs

Discussion

by Dr. Hal Hendrick
Past President, Human Factors Society

In general, I believe the article offers an excellent perspective. In several places, though, he appears not to be in touch with the current literature and terminology. Beginning with my second comment below, my comments address those places.

Page B-5, Designability: The author might also point out that, from a cost standpoint, it also is far, far cheaper to “do it right” at the beginning of the life cycle, rather than retrofit later (and provide the empirically validated rationale).

Page B-5, The Designer’s Working Environment: The author would be advised to use Alderfer’s ERG motivation model, rather than Maslow’s. Alderfer’s model not only is more recent, but it has empirically been validated to a considerably greater extent than Maslow’s. In addition, it covers situations which are not covered by Maslow’s - and was developed from actual industry studies, rather that clinical observations. Also, the author seems to have made a considerable stretch in equating “doing it right” with “self actualization” (i.e., many “right ways” which are designed into work systems are anything but self actualizing for the employees). The key is to design right ways of doing things such that they are motivational. This, in turn, requires beginning with a macroergonomic approach to work system design, and then fitting the hardware design to it.

Page B-6, The Designer’s Man/Machine Correlation: To begin, this is a way out of date label (1950’s). At the least, it should be changed to “Human-Machine Integration” in keeping with current terminology; this also reflects the fact that “integration”, rather than “correlation”, of the two is what is desired. In reality, what the author is really talking about is “human-system integration” (i.e. integration of the human component with all of the other system components: hardware, software, and environmental components). In fact, this systems approach should be even more strongly stressed here than it is. This also would be a good place to note the more important human factors design guidlines that readily are available to assist designers (e.g., Salvendy, Woodson, NASA, and the FAA design handbooks; the military HF design standards & handbooks; and the previously noted ASTM F1166-88 and Bea’s report SSC-378).

Page B-7: The Designer’s Job/Personality Correlation. The author would do well to review the literature, or summaries of it (e.g., The Annual Review of Psychology) in this area. In particular, the research over the past decade on the so-called “big five” personality factors and performance. It might interest the author to know that historically, the personality inventory that has been most predictive of job performance in various positions is the California Personality Inventory [e.g., see Clark & Clark (Eds.) (1990) Measures of Leadership, pp. 355-379.] Although the Myers-Briggs has been very popular, its usefulness as a predictor of performance in a given job is not as good as the CPI and measures of the “big five”. Also, although the way we verify it is via correlation, what we really are doing is ensuring a good job-person fit.