MARTIN OTTAWAY

The Need for Additional Human Factors Considerations in Ship Operations

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Abstract

The Shipping Industry has become more aware of Human Factors considerations over the last few decades. Today's ship operators have some familiarity with Human Factors in bridge operations and safety management systems, but there is little overall appreciation of Human Factors in ship operations. Today there are increasing indications that there is a growing disconnect between increased regulatory workloads aboard ships and the Human Factors response to this workload by vessel crews and operators. This disconnect expresses itself in overstressed ships' crews and frustrated ship operators. This paper surveys and analyzes Human Factors concepts as envisioned by IMO and other regulatory organizations and the shipping community's response to those mandates. The paper analyzes changes in crew tasks and workloads over the last few decades, and provides specific examples of Human Factors failures and successes in response to those changes in workload and makes recommendations for future considerations of Human Factors in ship operations and design. Specifically it recommends the universal formation of an environmental department aboard commercial ocean going ships to more efficiently deal with recently implemented regulatory requirements.

Keywords

Human Factors; Environmental Officers; Crew Training; IMO; Work Load

Nomenclature

HSI	Human Systems Integration
SEAPRINT	Systems Engineering, Acquisition and Personnel Integration

1. Introduction

Ship operations have undergone a very rapid change in the last twenty years. This change was driven by international demand to reduce maritime accidents and environmental impact. Most of this change was driven by introduction of far reaching regulations in the international setting, particularly through the International Maritime Organization (IMO). Starting in the early seventies, IMO entered a new field of operations by adding maritime pollution prevention as an area of involvement. (MARPOL, Segregated Ballast, Protectively located ballast tanks, Bilge water treatment). In the late eighties this focus became even more apparent when IMO responded to the United States' unilateral OPA90 regulation. US pressure to implement change put IMO center stage in the drafting of regulations to reduce both the risk and the consequences of maritime accidents. While part of these regulations were related to technical design (double hull tankers and IACS regulations), many, if not most, of these regulations (particularly ISM) focused on ship operations and, by association, human factors.

Since that time, most IMO regulations have signaled deep involvement in the design and operation of ships to benefit the public as a whole, rather than ship crews and passengers. There are significant indications that this change in focus has resulted in excessive burdens on today's ship's crews, and is resulting in a negative backlash at the ship operational level.

To some extent IMO is responding to the perception that crews are being overburdened even with some particular Human Factors initiatives (Ref: "Checklist for..."). Not only IMO, but also some flag state authorities are addressing Human Factors (Ref: "Human Element..." and US Coast Guard). Some of these efforts relate to particular human factors analysis efforts such as during accident investigations and with bridge team management, and some are evaluations of crew general welfare. However, so far, no real effort has been made to determine how crews can actually be helped through human factors analysis by studying the full spectrum of crew activities.

IMO has prepared a "Checklist for considering Human Element Issues by IMO bodies" IMO has agreed that this checklist should be completed by all relevant IMO

bodies before approving or adopting amendments to mandatory and non-mandatory IMO instruments. This checklist was approved on 22 May 2006 and it is not known if this checklist has been used in any new regulatory efforts. (This checklist will be further discussed in the SEAPRINT section of this paper.)

Within the Human Factors community an effort at increasing the overall efficiency of the human component on a particular system or designing the system with the human clearly in mind is called Human-Systems Integration.

This paper will define some of the factors that influence the Human-Systems Integration in ship systems and will provide some suggestions regarding promising areas of system modification, research, experimentation and development in HSI for ships and ship operation.

It is noted that these recommendations will be related to the commercial ocean going vessel. For the purpose of this paper these vessels are defined as ships that carry cargo on a world-wide basis and that have crews of between 10 and 30 officers and men.

2. Human Factors Description

2.1 Human Systems Integration

HSI sits at the core of applying Human Factors engineering and design. It really is intended to be the most encompassing systematic application of Human Factors knowledge. However HSI is still not that commonly applied, and is therefore rather difficult to define. Human factors engineering tends, by nature, to be more "fuzzy" than the "hard" engineering specialties such as naval architecture and marine engineering, but there are components of human factors engineering that can be relatively hard and even in the marine industry can be studied rather rigorously.

One such example is alarm and warning design, where real significant research has resulted in significant improvements and even standardization of warning and alarm systems. Another such area is bridge task management where one can take a ship simulator and run experiments to see how humans can best steer a ship.

These tasks are actual Human System Integration activities, but they tend to take a relatively narrow view and then study the human's interaction with that portion of the entire system. In recent years there have been some real improvements in the subsystems human factors integration, where the machine interacts directly with the human. This area is sometimes described as ergonomics, and recently some very useful guides and papers for this aspect of Human Factors have been published. (Guide for Crew … and the references in Hendrikse etal)

While these HSI efforts are helpful, they do not address the total system that is out there, which is a real ship, on the water, that is populated and operated by a small number of diverse people twenty four hours each day with hundreds of tasks that need to be performed and with hundreds of subsystems that need to be operated and maintained with very limited outside help.

That system is unique and has been subjected to tremendous change in the last few decades. There is an ironic twist with regard to this change if one realizes that in the not too distant past, the study of human-system integration was probably better developed in the shipboard setting than in any other setting.

This work was not identified as Human Factors research, but rather was called nautical literature and was practiced by Joseph Conrad, Patrick O'Brien, Herman Melville, Rudyard Kipling, Richard Henry Dana, Robert Louis Stevenson and many other great writers (including Guy Gilpatrick in his humorous analysis of the subject).

These works of literature are filled with observations regarding the interactions between ships and shipmates, and often serve as allegories for shore based human behavior. To a large extent these authors chose to write about ships because they realized that human emotions are amplified aboard ships due to the stress of the work, the environment and the close confinement of ships. While not formally grounded in principles of psychology, physiology and engineering, one should not underestimate the valuable contributions these authors have made to the understanding and the improvement of the ship system even though the improvements cannot be formally traced. Nevertheless, for example, it is well established that Dana's analysis of shipboard conditions in his "Two Years Before the Mast" resulted in very significant change in the role and protection of the seaman.

In contrast, this author is not aware of any authors who authoritatively write about the human condition in today's shipboard setting. While there probably are manifold reason for this lack of literary attention, one reason is probably related to the fact that if an author were to describe today's shipboard community, it would no longer deal with the tensions between shipmates, but rather deal with tensions between crew members and shore staff, crew members and port state control authorities, and crew members and paper work.

Possibly HSI aboard ships has become too complex for analysis by literary effort and we are faced with having to take a more formal approach. In actual fact, HSI on ships is so complex that it is not at all clear that one single optimal HSI solution can be developed for the ship system as analyzed in this paper. Nevertheless, as will be shown, even partial or relatively superficial analysis will provide important insights.

2.2 HSI Analysis

The US Department of Defense DOD instruction 5000.2c requires acquisitions involving humans to apply "a systems engineering process" to properly consider the human aspects involved. The Navy approaches this requirement with an HSI process that integrates the seven technical domains of human factors engineering, manpower, personnel, training, habitability, personnel

survivability, and safety/occupational health."[1]

HSI is excellently described in a PowerPoint presentation prepared by Dr. Folds of Georgia Tech Research Institute and is referenced below. The SNAME Human Factors T&R panel is taking steps in bringing HSI within the Naval Architectural domain, and further information is available on their website. For the sake of brevity, the intricacies of the method will not be repeated in this paper. However, some general discussion of the method will be of merit.

Like ISM, HSI is an analysis system. However unlike ISM, HSI is an external analysis performed by outside parties to make improvement to the system, rather than by the participants within the system. That does not mean that all stakeholders are not included, but rather means that there is an outside entity that coordinates all the various HSI activities.

To some extent, HSI operation is like the various management analysis systems like Six Sigma, but HSI takes a real look at the guts of the system (and very much from a human factors point of view), and will dig in at the engineering level at coming up with better solutions.

Most of all, HSI is a system engineering design and analysis method. It is not an equation based approach like finite element analysis, but it is more like the combination of art and science that occurs in yacht design. HSI is heavily promoted by the US Department of Defense and is incorporated into "SEAPRINT", which is an acronym for Systems Engineering, Acquisition and Personnel Integration, a program used by the US Navy to analyze system effectiveness at the ship procurement level (Ref: Dolan), which in turn is a development of the US Army's MANPRINT. SEAPRINT is a rather recent development and has not been fully implemented within the US Navy structure and actually now appears to have been discontinued. While not developed for analysis of existing systems, SEAPRINT provides a useful starting point for HSI analysis of commercial ship systems. As such, the SEAPRINT approach has been used in the below analysis, but working definitions have been adjusted, as needed, to allow analysis of commercial shipping.

2.3 SEAPRINT description and use

In essence, SEAPRINT is a bookkeeping system that allows the engineer to perform his "deep think" on a particular problem not unlike the use of a design spiral in ship design. The concept behind HSI is to put human factors considerations on the design spiral to ensure that the human component of the design is adequately addressed, evaluated and integrated. (Ref: Landsberg)

SEAPRINT assists an engineer/human factors expert in reviewing the various human system integration components that are associated with the ship system procurement and design.

SEAPRINT specifically reviews the categories as shown in figure 1. Upon completion of the review the engineer is tasked with making improvements to the system to end up with a more efficient overall human system integration.

Rather than applying SEAPRINT to new construction as intended under the original US Navy application, this particular paper will use SEAPRINT to compare today's ship system against the ship system of the early seventies, to identify problem areas and to suggest solutions with an ultimate objective of decreasing the environmental impact and increasing the efficiency and sustainability of international maritime commerce. In essence SEAPRINT is used to make a design comparison between ships of the early 70's and ships today.

This comparison supports the apparent intent of the IMO "Checklist for considering human element issues by IMO bodies". Whether intentional or not, the review items under item 11 of the checklist are almost identical to 6 of the 7 SEAPRINT categories (the IMO review items omit "Safety", but this is to a large extent included under IMO's own stand alone regulations) As such, the work in this paper provides a baseline IMO human element issues review for *existing* IMO regulations, rather than new IMO regulations.

It is also intended that this review will assist in increasing the profitability of those operators who recognize that the marine industry is rapidly changing and that rapid response and adjustment to change will result in increased profits.

It is noted that the increase in profitability can be measured in overall reduced costs of operating the ship and increased personnel retention, but also in the reduced costs associated with avoidance of litigation, physical and commercial damages and fines (especially pollution fines).

3. SEAPRINT Analysis

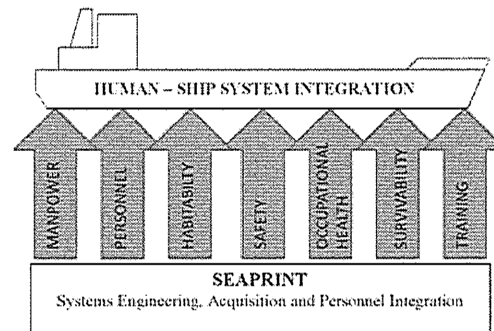

Figure 1. SEAPRINT components

The below SEAPRINT analysis is based on a general evaluation of ship system changes that have occurred in the last twenty to thirty years. This review does not use

[1] *The definition is ambiguous by not noting if engineering is one of the technical domains, or if the subsequent seven (eight) domains are subgroups of human factors engineering. It also does not provide any guidance as to how HSI is to be performed.*

a large amount of statistics, both because the intent of this review is to perform a general analysis, but also because, at this stage, there has not been a significant amount of numerical or statistical research that has been performed on the subjects that are addressed in this paper. Since SEAPRINT was developed for NAVY ships some of the category definitions have been amended to include commercial shipping concerns.

The review progresses along the above noted SEA-PRINT categories.

3.1 Manpower

SEAPRINT defines manpower as the number of personnel, type of personnel (military, civilian and contractor), required, authorized and potentially available to train, operate, maintain, and support each deployed system.

For commercial shipping this definition would require a small adjustment as follows:

> ***Manpower: the number of personnel, type of personnel (shore based, shipboard and contractor), required, authorized and potentially available to train, operate, maintain, and support each deployed system.***

While there always has been great variety in the manpower make-up of commercial shipping, there is no doubt that the last few decades have seen a specific trend towards smaller shipboard crews.

In the early stages of that trend the reduction in crew was related to increases in automation and improvements in reliability of ship equipment (Ref: Gaffney and Yamanaka). This reduction in manpower happened incredibly fast since it provided immediate savings to shipowners.

Vessels	'79	'82	'84	'85/UMS
ULCC "B/SPLENDOUR" 360000 dwt	42	29	27	–
VLCC "E/EVOLUTION" 230000 dwt	40	29	27	–
M/TKER "CYS TANKER" 29000 dwt	37	27	25	20
CONTAINER "O/COMMANDER" 27000 dwt	33	27	24	17
PANAMAX BULKER "CHINA TRADE" 63000 dwt	–	–	22	–
G.C. "ATLANTIC CHARITY" 12000 dwt	33	28	21	17
CAR CARRIER "TOYOTA NO.23" 11000dwt	32	26	24	–

Figure 2. Manning reduction evolution on representative CMT vessels (Ref: Gaffney and Yamanaka 60)

However, since the late eighties ship's crews have faced increased administrative and watch keeping burdens and increased operational tempos (MARPOL, ISM, ISPS) without increases in crew size.

This reduction has been accompanied with somewhat of an increase in shore based staffs, and more significant contractor involvement in specific systems, but undoubtedly shipboard officer's workloads have increased.

Ship's crews have been reduced from around 30 (45-20) to around 15 (22-10), and while one port engineer (or port captain) often ran as many as 10 ships, today the shore side staff includes much more substantial human resources to address the risk, safety and administrative issues and port engineers more commonly now cover 3-4 ships.

Specifically, the shoreside staff has acquired the new legally required position of Responsible Person, and the shipboard staff has lost the position of Radio Operator.

The Radio Operator was deemed to be superfluous due to increased automations of radio equipment and the position was eliminated as a statutory requirement in 1990's. Undoubtedly ship to shore communications have become more effective and redundant, but at the same time deck officers have taken over part of the role, in addition to their existing duties, through GMDSS certification. If operational, almost anybody can use today's ship to shore communications equipment to contact the shore. However, in general, the amount of shipboard communications required with shore based entities has severely increased and in addition the amount and type of communications equipment required aboard ships has increased (AIS, for instance as but one example). This has resulted in a significantly increased burden on ship's deck officers, and increased need for the technical skills that are normally associated with the radio officer.

In addition, the radio officer often served as an administrative assistant to the Master, at least in maintaining correspondence and communication logs. This task has also been fully assigned to the Master, and today the Master also has responsibility for the additional administrative tasks associated with ISM and other emerging regulations with administrative components.

The ship's deck officers have encountered similar increases in workload, whether related to administrative tasks, or actual supervisory tasks related to new regulations such as ISPS ballast water management or MARPOL garbage logs.

With regard to the engineering staff, similar increases in work load have occurred. While automation, in theory, reduced workload, not all automation is a net benefit. This is often illustrated when shipboard engineering staff disables a certain automation or alarm system either because it does not work as desired or it results in too many false alarms. At the same time, automations have significantly changed the engineering staff's type of work, which originally focused on equipment operations and watch standing, but today mostly encompasses diagnostic and maintenance function. The introduction of automation on propulsion systems reduced the need for manpower aboard ships and this was appropriately implemented in the 1970's. However, in general, the number of specific systems that require maintenance aboard a vessel has increased and, while often automated to a significant extent, these additional systems also increase the operational workload for engine room

personnel.

The following systems have only recently taken a prominent position aboard ships and now require diagnostics, operation, record keeping and maintenance in addition to more traditional ship systems.

- Oily Water Separators
- Incinerators
- Heavy Fuel Oil Treatment equipment
- Sanitary Systems
- Emissions subsystems
- Elevators
- Dynamic Positioning Systems
- Thrusters
- ISPS
- Port State Reporting Requirements
- GMDSS
- ISM
- Ballast Water Exchange
- Computers, photocopiers and printers
- Garbage processing systems
- Tank cleaning systems
- Tin free antifouling systems
- Chlorofluorocarbon refrigerant replacement
- Double hull tankers (and bulkers)
- SOPEP and VRP's
- Closed loading systems
- Cold ironing (future)
- AIS

While mention of photocopiers and printers might be considered to be trivial, it needs to be remembered that those systems are an integral part of today's ship system, and installation of a new printer, by nature, will be more time consuming at sea than ashore and even the most capable ship's engineer will face the same frustrations that any shore based engineer will face, but with the added frustration of not being able to return the printer to the store or to call the office IT officer. A ship's engineer can easily spend a full day trying to install a printer or a new piece of software, and this distraction can have significant follow-on effects in other required tasks.

Elevators are mentioned to illustrate that technical design trade-offs can be difficult to make. In theory, an elevator will reduce a crew's workload if the elevator runs reliably and if the elevator actually decreases a crew member's time in transit between decks aboard a ship. However, in shipboard service, an elevator can add a significant maintenance burden, decrease crew fitness, and can actually increase transit time between decks if one takes into account the time waiting for elevators to arrive and deciding whether to continue waiting for the elevator or taking the stairs is taken into account. This is a complex function and can vary heavily from ship to ship depending on crew culture, crew size and usage patterns.

Even with the best of intentions, it is entirely possible that certain apparent improvements such as elevators are actually detriments to the efficient operation of a ship.

Some of the systems that have been added to modern ships serve no direct benefit whatsoever to the crew. Oily Water Separators, incinerators and sanitary systems do not make the ship go faster, or make it more efficient, at least from the ship's, or ship owner's, point of view. They mostly exist for the benefit of the public (in reducing pollution). While the motivation for properly operating the main engine is clear and direct to a vessel's crew (if the engine does not work, my boss will not make money with the ship and I will lose my job and, furthermore, when the engine stops working everybody will know it), the motivation for proper operation and maintenance of systems that exist for the public is not so direct and clear (Does my boss really care if I operate those systems properly? Who will notice if I do not operate them properly?)

Recently increased inspection and evaluation of the "public" shipboard systems has resulted in a shift in crew attitude towards those systems. At this stage it can be firmly concluded that crews have gone from ignoring the OWS for decades to increased vigilance in the last decade. However, at this stage, it is not clear whether this increased vigilance is related to proper operation or avoidance of detection of misoperation. Regardless, this latest trend in enforcement has increased engine room workloads.

With regard to workload analysis, this author has not been able to locate any specific studies that provide any type of guidance as to what today's actual crew workloads are.

Workload for the purposes of determining Navy manpower is defined as follows:

Crew workload = OM + PM + CM + OUS + FM + PA + SD&T

Where:

- OM - Operational Manning (watch standing)
- PM - Preventive Maintenance
- CM - Corrective Maintenance
- OUS - Own Unit Support (laundry, food services, medical, religious services, etc.)
- FM - Facilities Maintenance (painting, cleaning, swabbing)
- PA - Productivity Allowance (a factor of inefficiency or unaccounted for crew tasking)
- SD&T - Service Diversion and Training (service time allotted for infrequent duties such as escorting ship visitors, job and skill training, etc)

The usual expression of workload in any of these areas is hours per week. (Ref: Khandpur) Paper work is probably included in Operational Manning, but it is important to note that paper work is portable, and therefore might not be readily identifiable in a workload analysis. Occasionally there are attempts at defining the amount of time associated with workload such as the paper work reduction act notes that occur at federally issued forms and logs, but they can be wildly unrealistic. For example the latest US Oil Record Books note the average burden for this report is 2.5 minutes. It is not clear what constitutes "a report", and it is not known who established that the average burden for a report is 2.5 minutes, but even one entry takes more than 2.5 minutes to prepare when the entire manpower/recording chain is included.

In order to provide a higher level of analysis, possibly for commercial shipping the workload definition should include RD – Reporting Duties, and possibly PD – Public Duties, which are not ship mission workload related, but rather relate to duties that that fit under the various IMO directives that serve the public rather than the ship.

The latter is not a show of contempt for Public Duties, but rather is meant to support system improvement suggestions as will be shown later. Workload can then be expressed as:

Crew workload = OM + PM + CM + OUS + FM + PA + SD&T + RD + PD

Actual crew workload analysis on ships can be a frustrating exercise since the tasks are varied, large in number, irregular and crews are small. This author is not aware of any overall crew workload analyses that have been performed on commercial vessels, and recommends that such be performed since they could provide very significant insight into the root causes of many perceived issues with regard to manpower in the maritime community.

It is noted that the IMO has issued watch standing standards under STCW. These standards are realistic, as long as one assumes that officers will only stand watch in the operation of the ship system. Unfortunately ship's officers do not just stand watches, and, as such, it is entirely possible that while ship's officers are not exceeding watch standing periods, they are not entirely keeping up with their rest periods and instead are doing paperwork in their cabins instead of getting sleep or performing maintenance tasks.

While attending aboard ships, this author has encountered various occasions where it was physically impossible for a ship's officer to comply with watch standing and rest periods, and, at the same time, to be able to keep up with paperwork, security, cargo handling, communications and inspection duties. On some occasions there was clear evidence that the officers were adjusting their record keeping to fit within the standards and there were officers who admitted to not being able to meet the standard on a regular basis. Ironically not meeting watch keeping standards would be a non-conformity under ISM and as such should be logged under the safety management system for further evaluation and remediation. To date this author has not encountered any records of such non-conformities during vessel inspections.

The above discussion relates almost entirely to ship's officers. Ship's non-officer crews (ratings) have also been reduced over the years. While there are fewer indications that the reductions in ratings have resulted in increased workloads for ratings, further investigations would certainly be warranted.

There is no doubt that the ratings' tasks have not changed as drastically as those for the officers in recent years and ratings tasks are generally specifically related to manual functions that are directly associated to time on and off duty. As such, ratings might have been less affected by recent ship system changes than officers.

However, lower numbers of ratings and lower skill levels of ratings (often seen by the absence of a true Bosun aboard a vessel) can result in further additional workload for officers. Where, with larger complements of ratings, officers would have delegated a task, today the officers might be assuming tasks that were originally performed by ratings.

With regard to ship system manpower, one should not just consider the ship complement, but also the shore staff and outside contractors. In theory, the shore staff is a ship support staff. The shore staff exists to take on duties that are more effectively performed ashore. A classic example of such a task is related to port engineering. Traditionally, the port engineer monitors the level of maintenance of a vessel, investigates possible improvements, ensures that the ship receives appropriate maintenance assistance upon arrival in port and organizes major shipyard periods. In essence, the port engineer is a ship's shore based support, the first confessor for the Chief Engineer. While ideally that relationship still exists, today, due to increased record keeping requirements and improved ship to shore communications, the task of the port engineer has also changed and now he is deeply involved in ensuring that paperwork requirements are up to date and that the vessel can pass emerging standards that have come into effect in the last few decades.

It has become much less common for port engineers to be able to attend aboard a vessel and to simply sit and communicate with the chief engineer. Instead often vessel attendances are associated with a rushed inspection according to a specific checklist, with an aim to prove, by filling in the checklist, that the vessel complies with one or more of many standards. While these requirements, together with third party vetting and port state vetting requirements have increased, in port times for ships have decreased. As such, actual support by shore staff for shipboard crews has probably decreased.

Undoubtedly outside contractors provide support to ships and crews, but even outside contractor support can become problematic in today's operational setting. Increasing numbers of shipboard systems and increasing complexity of those shipboard systems increases the

need for attendance by outside contractors when the vessel arrives in port. However, increasing numbers of outside contractors attending, combined with ISPS, reduced crews and reduced times in port, make scheduling of outside contractor attendance a nightmare for ship's crews. Often, due to other in port demands on the vessel crew, an outside contractor performs an adjustment or repair without attendance by a crew member, which in turn does not provide the ship's crew with any type of feedback on the type of adjustment or repair that was made, or if the adjustment or repair was performed correctly. Furthermore, it prevents a crew member from learning from a contractor about a particular system which then will require further contractor attendance in the future. Ironically, a shoreside contractor who is not accompanied full time by a crew member could also constitute an ISPS violation.

Today the system has reached the point where port support by outside contractors is deferred simply due to too many other in-port commitments. While, in theory, some contractors could ride the ship to perform their task, this inherently is very expensive and is avoided by ship operators at all cost.

Ironically, the above discussion of issues is not new. Yamanaka and Gaffney provide a fascinating discussion of effective manning analysis in "Effective Manning in the Orient" which was written in 1988 and shows that the manning reductions of the eighties were not arbitrarily chosen, but instead, were the result of deep discussion and quite rigorous analysis and testing. Oddly, this author has not found any more recent papers on the subject and it appears that manning analysis has simply become a forgotten art.

The above manpower discussion has dealt with operation, maintenance and support of the ship system, but, by definition, manpower analysis also deals with manpower availability and the ability to train.

Today, general manpower availability for ship operations is one of the critical issues in our industry. There are real indications that there is, or at least will be, a significant shortage of manpower to operate and maintain ocean going ships. The cause of the lack of generally available manpower is complex, but undoubtedly is related to some of the factors described above. However, it is also related to other HSI factors that will be discussed below.

Similarly, training will be discussed further below, but under the manpower category it is noted that shipboard training is essential to efficient ship operations. Shipboard training requires officers and crew experienced in training, trainable crew and contact time to perform training. In the rare case that training is recognized as a real manpower component, there is a tendency by operators to assume that training time is a formal time period that is scheduled in a work day. Research by Klein and others has shown that in the type of operations that are associated with shipping, actual training in non-formal settings is often more effective. Klein particularly identifies this is his studies of fire fighters and the value of story telling in the fire house while crews are not actively engaged in fire fighting. Similarly ships crews used to benefit from discussions about ship operations in down time, during shared watch standing periods, during shared meals and during shore excursions. All these settings have become almost non-existent in present day ship operations, and it is noted that actual person to person training time, whether between port engineers and chief engineers, ship staff and contractors, officers, cadets and crew has drastically reduced in recent decades. There have been attempts to substitute this function by means of shipboard computerized or video training courses. However, while there are many situations where these courses can be valuable additions to mentor/mentee training time, they cannot substitute for the latter. This concept will be further discussed under Habitability and Training below.

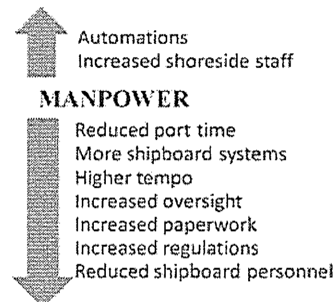

Figure 3. Changes in manpower requirements

3.2 Personnel

SEAPRINT defines personnel as the human knowledge, skills, abilities, and cognitive and physical capabilities required to operate, maintain, and support a system in peacetime, contingency operations and conflict.

For commercial shipping this definition would require a small adjustment as follows:

> ***Personnel: The human knowledge, skills, abilities, and cognitive and physical capabilities required to operate, maintain, and support a system in normal and contingency operations.***

Just like there has been a shift in manpower requirements there also has been a shift in personnel requirements in the last decades.

Not too long ago, a proper ships system consisted of a crew of a particular nationality that was managed by a shore staff of similar nationality. These crews were trained to standards and systems that were implemented by the ship's flag state and also enforced by that flag state.

The international involvement of a ship related to the Master's ability to speak English, and possibly some other languages within his operating area, and with the crew's ability to go ashore in various ports to be able to sample the local culture and to obtain additional language skills (often English also in most major seaports).

If crew members of a different nationality were engaged aboard a ship, it was generally in a rating capacity rather than an officer's capacity.

International registries started to blur the national line, and this resulted in multiple nationalities, with different cultures and different levels of training operating one ship. In addition, international registries depend less on simple seniority systems and, as such, crew members achieved more senior positions more rapidly, and with less oversight as far as evaluation of skills within a ship system was concerned.

Shipping inherently comes in unlimited variations, and, as such, it should be noted that not all international registries or operators under international registries are of lesser quality than national registries, but there is no doubt that once a crew member is removed from his own national culture he has to deal with new standards, dynamics and methods. All of this requires additional learning, and adds additional stress, whether related to learning a new language, to dealing with different cultural standards or to adjusting to different foods. All these hurdles can be overcome by a sufficiently motivated seaman and ultimately will result in a more capable and flexible world citizen. However, it takes time and effort and cannot be accomplished overnight.

Not too long ago, if one asked what type of person would go to sea, the answer would probably include the following factors for a rating:

1. A desire to make a decent living
2. The chance to get away from wherever they were (for whatever reason; family, a bitter conflict)
3. The chance to see the world
4. The chance to save a little money
5. No problem with being away from family and friends for an extended periods of time
6. Physically able to deal with the hard work at sea

The following slightly different factors would probably apply to officer candidates not too long ago:

1. A desire to make a decent living
2. A desire to get into the middle class at home
3. The chance to see the world
4. The chance to gain the respect of those who stayed ashore
5. The chance to acquire skills that will be in demand in the home country
6. No problem with being away from family and friends for extended periods of time
7. Intellectually able to learn the managerial and technical skills required in operating a ship
8. Physically able to deal with the hard work at sea
9. The rights and privileges accorded an officer and the possibility of independent command

Today these factors have changed. For ratings the change is modest, but not positive. The most obvious change is that, today, in commercial ocean shipping it is almost a given that ship's crews have almost no opportunity to see anything of the world. Reduced port times, increased port duties and increased security restrictions have made shore time a rare occasion indeed. Furthermore, overall availability of overseas work and travel has removed this motivation for going to sea almost completely. Why go to sea if one can work as a guest worker overseas or simply buy a $300 airline ticket and a backpack and see the world on one's own terms?

At first glance the major difference for the officer is a similar loss of opportunity to see the world, and a much higher need for training due to reduced specialization and more complex and a larger number of installed ship sub systems. However, the actual work description of the ship officer position has changed so drastically that an entirely different type of person has become the ideal candidate.

Where previously a ship owner would try to select those individuals who are capable of operating independently and at their own initiative (as per the traditional definition of an officer), today's ship officer is ideally a person who is risk averse and responds well to specific directives.

Where in the past one could describe the ideal ship's officer as follows:

1. Independent
2. Self motivating
3. Capable of developing individual solutions to emerging problems
4. Capable of operating away from support networks
5. Innovative
6. Hands-on rather than paperwork driven
7. Ability to work in small tight teams

Today the ideal ship's officer would be something like:

1. Independent so he can survive in the marine environment, but not so independent that he will ignore daily shore side directives.
2. Self motivating in ensuring that he will readily respond to all the demands that are made on him, but not so self motivating that he will develop independent work schedules, methods and solutions that might not necessarily be in conformance with thousands of pages of written directives.
3. Capable of developing individual solutions when everything goes wrong and when there is no written directive that applies, but not trained or asked to develop independent solutions when there are written directives, and willing to submit to criminal prosecution when he develops the wrong individual solution.
4. Capable of operating away from support networks, but not allowed to be away from intrusions 24 hours per day.
5. Innovative if working for ship owners who are interested in cutting regulatory corners, but not when working in the highly formalized environment of the ship owner who wants to conform to every regulation that applies to their

operation.

6. Still hands-on, but at the same time capable of dealing with huge paperwork demands.
7. Get along with the ship team, but most of all get along with inspectors, shore based managers, and regulatory enforcement officials.
8. Be a natural linguist able to communicate in almost a random number of languages with the ship's crew, but most of all have a natural ability to speak English.

This description has become highly schizophrenic and it is unlikely that a sufficiently large supply of such individuals exists in the world.

Most of all, the above description is a nightmare scenario from a personnel management point of view. In essence, the industry is asking for sensitive, subservient but technically capable problem solvers to operate in an environment that traditionally has asked for people that have a strong independent streak and the ability to make decisions contrary to shore based instructions if such a decision is warranted due to emerging onboard conditions.

Shipboard personnel recruitment has become a bad advertisement that appears to show ships, international commerce, oceans, and advanced equipment but is hiding the actual truth that actually consists of dirty work, high stress and filling out paperwork in one's cabin.

Not only ship's crews are frustrated. At a recent ship conference one ship manager was reported as stating that "if seafarers act like mercenaries and prostitutes that's how they themselves will be treated" and claiming that crews are getting too "choosy" and are demanding too much (Ref: Pickles). Statements such as these are significant indicators that a more detailed analysis of the ship HSI is required to determine whether there is any significance in such statements.

There are two potential solutions to the recruitment problem. One can start a massive campaign to correct the flawed perception of the shipboard officer's life and simply look for the right type of mechanically subservient individual that could fulfill the requirements for shipboard officers, or an effort can be made to remove the schizophrenic aspects in the shipboard officer's job description.

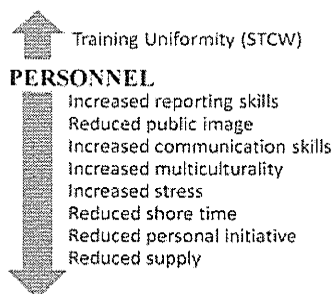

Figure 4. Changes in personnel requirements

As far as job description is concerned it would be unrealistic and even counterproductive to ask for complete elimination of the recent changes in shipboard operation and to return to the past. The world has changed too much to allow for this change and it would remove the apparent significant strides (or, at least, wobbly first steps) that have been made in reducing ship system environmental impact.

It is highly unlikely that there will be many applicants if one were to clearly describe today's shipboard reality and as such it will be necessary to make improvements in the shipboard employment environment.

3.3 Habitability

As applied to commercial shipping, the SEAPRINT definition of habitability requires no adjustment.

> ***Habitability: The characteristics of systems, facilities, personal services and living conditions that result in high levels of personnel morale, quality of life, safety, health and comfort adequate to sustain maximum personnel effectiveness, support mission performance, and avoid personnel recruitment and retention performance.***

It is noted that the habitability definition includes quality of life considerations. There have been very reasonable suggestions to rename this domain to "Habitability and Quality of Life" to elevate the significance of quality of life in this domain context. The author has elected to retain the single word name for this domain for the sake of brevity but at no time should it be interpreted as a lack of consideration for quality of life issues.

Insofar that habitability describes the ship's accommodations, based on physical aspects alone, there have been significant improvements in habitability aboard ships to the extent that, today, commercial vessels are much more likely to have air conditioning, individual cabins, consistent food quality and reduced ambient noise, and, due to generally increased ship sizes, less fatigue due to ship motions.

However, have these changes resulted in an improvement in the crew's working conditions?

The ship's accommodations serve a wide variety of functions, such as:

1. A place to sleep
2. A place to work
3. A place to eat
4. A place to socialize
5. A place for personal needs
6. A place to train and learn

Undoubtedly, for the most part, today's accommodations show improvements in items 1, and 5. Overall physical design of accommodation is poised to improve with increasing prevalence of guides for crew habitability aboard ships (Ref: Guide for crew…") and greater awareness of appropriate physiological standards (Ref: "Ship Design and Construction"). However, items 2, 3, 4 and 6 have not necessarily improved. This is not due to any changes in accommodation design, but rather in changes in shipboard work requirements and changes in

communal behavior that have developed ashore also.

For example, improvement in entertainment electronics have increased TV and video watching and have resulted in changes that are also evident in shore based communities. Aboard ship this means that there is substantially less crew to crew contact than in the past. A few decades ago it was not unusual to encounter interesting conversations in crew and officers' messes while today the messes are a waste land most hours of the day.

Crews go on watch, work and go to their cabins. In many ways this reduces tensions, but it also has significant adverse effects.

Reduced crew sizes have resulted in less personal contact during work shifts. Where not too long ago, multi person watch standing was common, today many watches are solitary affairs.

The obvious effect is that watch standing is simply less enjoyable, but more importantly it is also detrimental to training of more junior crew.

Just about every change aboard ships has reduced social contact. Even air conditioning has unexpected results. In old ships without adequate air conditioning crew members congregated in areas where there was a breeze, but plentiful air conditioning allows crew members to retreat to their single cabins behind closed doors to pursue their pastimes or to attend to paperwork.

Occasionally one encounters interesting efforts at increasing crew social contact. Ships with combined engine and deck offices enhance crew contact, and this author also was impressed with the effect of a combined engine control room and cargo control room/deck office in one ship built in the middle seventies.

American ships serve food cafeteria style. This might appear to be a detriment from a "style" point of view, but it promotes direct contact with the galley staff and enhances contact between officers and ratings. The ability to compliment a cook on a particular menu item and to reinforce the community aspects of meals by serving meals from a serving station and returning dirty dishes to the galley provides much needed ship board interaction.

Ship habitability design has progressed piecemeal without close analysis of the actual needs of ships crews in today's operational setting. The time has come to take a close look at what can be done to integrate the actual needs of the crew with the physical structure that sticks out above the main deck.

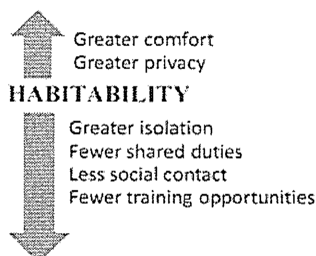

Figure 5. Changes in habitability conditions

3.4 Safety

As applied to commercial shipping, the SEAPRINT definition of safety requires no adjustment.

> ***Safety: The system design characteristics that serve to minimize the potential for mishaps causing death or injury to operators, maintainers, and support personnel or threaten the operation of the system.***

Safety appears to be one domain where recent efforts have been successful. Safety used to be a subject that received lip service by ship's crews, but, to a large extent, was fatalistically ignored. In recent decades especially P&I clubs have made a significant effort at reducing work related injuries through promotional and educational efforts. In addition both the design of lifesaving equipment and STCW required survival training have significantly reduced crew casualties, and while no recent data regarding the effectiveness of ISM is available, ISM has certainly brought the subject center stage.

While safety used to be a national culture where certain flag states were vigilant in ensuring that safety equipment was well maintained, today, through port state control inspection, all ship of all flags have learned to become more attentive with regard to safety items.

Still safety is a culture. It requires continuous drill, encouragement and reinforcement at all levels and should not just be an effort that aims to have everything ship shape when the ship approaches a port that has a high level of safety requirement enforcement.

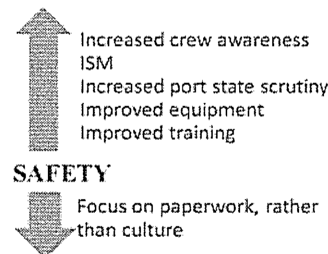

Figure 6. Changes in safety characteristics

3.5 Occupational Health

As applied to commercial shipping, the SEAPRINT definition of occupational health requires no adjustment.

> ***Occupational Health: The system design features that serve to minimize the risk of injury, acute or chronic illness, or disability; and/or enhance job performance of personnel who operate maintain or support the system.***

Within the ship system, occupational health is very similar to safety, except for chronic exposure issues. In recent years there has been a very significant effort in reducing chronic exposure issues especially at reducing exposure to potentially hazardous materials and noise. Asbestos exposure is pretty much a thing of the past and even environmental enhancements such as Closed Loading Systems (CLS) also benefit crew members.

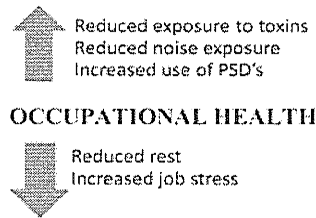

Figure 7. Changes in occupational health conditions

However, increased tempo, ever increasing skill requirements and potential for criminal prosecution in foreign countries do add significant levels of crew stress with associated detrimental health effects. While shipboard heart attacks and suicides are not a recent occurrence, this author is aware of crew heart attacks and suicides that were directly related to events that were precipitated by enforcement of recent regulations.

3.6 Survivability

SEAPRINT defines survivability as the characteristics of a system that reduce fratricide, reduce detectability of the system and/or personnel, prevent attack if detected, prevent damage if attacked, and minimize injury.

Within the commercial shipping context this definition is not particularly applicable. Nevertheless there are some survivability aspects that do come into play within the HSI analysis of commercial shipping and, as such the definition is provided as follows:

> ***Survivability: The characteristics of a system that reduce injury and harm to the environment during normal operations and in case of a mishap.***

Instead of a ship centric perspective, this domain now takes a whole earth perspective, which appropriately mirrors recent changes in the commercial maritime industry. As modified, this domain can be described as environmental survivability, as in the ability for the environment to survive with the lowest level of ship system impact. The relatively recent introduction of this domain in the ship system has been a very significant development that impacts much more than the ship, the ship operator or the shipping industry as a whole.

While the world bickers and struggles with Kyoto and other environmental issues, the international shipping industry under IMO has simply marched from one environmental improvement to the next, and includes the following recently introduced sub systems:

- Garbage processing systems
- Tank cleaning systems
- Ballast water treatment and exchange systems
- Bilge water treatment
- Exhaust emission control systems
- Incinerators
- Tin free antifouling systems
- Chlorofluorocarbon refrigerant replacement
- Double hull tankers
- SOPEP and VRP's
- Closed loading systems
- Cold ironing
- Sewage and sanitary systems

In many ways these regulations are a magic bullet that unifies the world in its improvement of environmental survivability. Crews who have learned to deal with and protect the environment aboard international ships and in international ports will be more able to affect similar positive environmental survivability changes when they return to their home countries (As long as crews have been properly trained, that is). One cannot underestimate the impact of an environmentally well trained ship's engineer who becomes a power plant or factory engineer in his home country when retiring from the sea.

Taking into account that the marine industry is an international environmental leader, it also carries the burden of getting the Human Factor component in this domain to work as well as possible.

With regard to the HSI analysis, the above sub systems have a mixed effect aboard the ship.

Some of these sub systems, such as the elimination of tin free antifouling coatings has been almost invisible to the crew and have resulted in direct and immediate domain improvements. The elimination of tin based antifoulings has not increased crew workloads, not increased personnel demands, not reduced habitability, and possibly has increased safety and health, all without significant training requirements. While the technical transition was difficult (and initially might have had a negative effect due to increased hull drag with early transitional technologies, and significantly increased costs), the newest tin free technologies appear to have multiple benefits such as reduced hull drag, reduced toxic impact and reduced shipyard periods (although reduced shipyard periods could actually entail some negative crew impact)

On the other hand, some of these subsystems, such as bilge water treatment and management, have deeply affected the HSI of the ship system, and do not appear to have arrived at any workable solutions at this stage.

Others, such as ballast water treatment and exchange sub systems, impose a significant burden on crews and are technically still immature. At this stage, crews are faced with a rather complex additional operational routine that has increased manpower and personnel demands and actually appears to have reduced safety (COUGAR ACE incident). Ballast water treatment and exchange is still in technical flux, but it does not appear to be solvable in a "one solution fits" all approach, which then will significantly impact training requirements.

Undoubtedly most of these sub systems have added a significant burden to ship's crews and there are no indications that there have been adequate adjustments in the HSI for the ship system.

One additional recent regulation, ISPS, also should be noted under this domain in that it deals with survivability, but only marginally with the environment (ISPS could prevent environmental terrorism). From an HSI point, ISPS is similar to the above mentioned sub systems in that it tends to increase the vessel's workload, but only provides a very limited direct benefit to the crew.

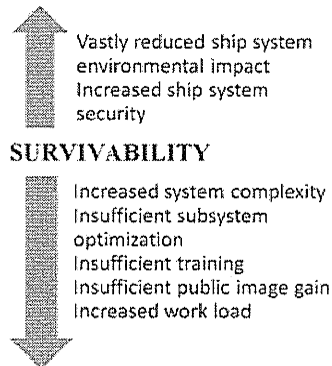

Figure 8. Changes in survivability conditions

3.7 Training

SEAPRINT defines training as: The instructions and resources required to provide (Navy) personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support (Navy) systems.

In spirit, simple deletion of the Navy reference will make this definition directly applicable to commercial shipping. However, whether due to Navy culture or by simple omission, this definition appears to focus almost exclusively on "instructions" which can be interpreted as written documents, rather than the pantheon of possible instruction methods, as such, for commercial shipping, the definition is modified as follows:

> ***Training: The resources and methods required to provide personnel with requisite knowledge, skills, and abilities to properly operate, maintain and support the ship system.***

Ship's crew training is unique in that it has an exceptionally high level of certification even going back as much as a century. However, besides formal certification, which, to a large extent, relies on formal education, the majority of crew training takes place aboard the ship system. Traditionally training consisted of a certain period of shore based training (as little as an elementary school education to as much as college level maritime academy training) followed and interspersed with shipboard time. Shipboard time was always related to actual shipboard work, but the work itself was designed to be part of a training setting.

Regardless of rank, position, nationality, or culture, shipboard training came from the top down, where knowledge flowed from senior rank to more junior rank. This could relate to able seamen teaching ordinaries how to splice, up to a Chief Engineer showing a 1st engineer how to deal with excess cylinder liner wear in a particular engine.

This process used to be extremely effective and as long as ship system technology and sub systems were relatively stable, allowed for excellent transfer of knowledge and skills. However, with rapid changes as noted above, this system has become unstable. This can best be described by noting that a new ship subsystem will be new to all personnel aboard the ship. As such, the Master or the chief engineer cannot function as the authority on that sub system and faces a number of stressful choices. He can choose to hand the responsibility to a more junior officer, but this removes his authority in decision making since he will not have the knowledge to determine whether the junior officer is taking correct actions or not. He can choose to learn as much as possible about the system and then train his crew, but since his operational experience is no more extensive than his crew this can quickly result in improper or incorrect operational practices. Furthermore, this approach adds very significant workload burdens to the senior officer. As a last alternative, he can choose to ignore the system, claim it does not work properly or fake its proper operation. Since the designer of those systems rarely gets to test it in real operational conditions it will be almost impossible to determine whether these systems work or not. While this uncertainty exists, the senior officer can direct his attention to other problems unless he is put under pressure by other motivators such as criminal prosecution.

Regardless, it can be seen that the onboard training process on new systems is inefficient and shore based training on many of these systems (OWS, ballast water exchange, exhaust emission control systems) is difficult if not impractical due to the difficulties of creating realistic training conditions.

With regard to training and certification, recently there has been greater standardization under STCW. While STCW acknowledges the need for shipboard training, the regulation focuses on shore based training and certification. STCW is a significant step forward in providing an international standard of minimum training, but there is no indication that the STCW minimum required training is sufficient for proper ship operation. STCW sets a baseline, but does not address all the systems that compose today's ship system.

Despite efforts to provide enhanced shore based training and interactive and video ship based training it is almost certain that on the job ship based training will continue to be a major factor in international shipping.

This conclusion can be supported by knowing that with increasing system complexity, increased on the job training is required. Therefore driver education (operation within a very complex system) proceeds with a very large on the job training component (Driver training under instructor supervision), professional engineer training takes place on the job (In the US: four years of college and at least five years on the job) and submariner training takes place mostly on the job.

In this regard HSI in the training domain for ship systems is of vital importance, and will become progres-

sively more important with increasing system complexity. Therefore, the ability to train crew aboard today's ships (and possibly ashore) warrants further investigation.

The following factors affect shipboard training effectiveness:

- Senior to junior contact
- Senior and junior time to provide instruction
- High skill levels in senior personnel
- Motivation to train
- Motivation to learn
- Training skills
- Communication skills

Even cursory examination shows that these factors have been negatively affected with recent ship system changes.

Single man watches, lack of common rest time in common rest areas and reduced crew sizes have reduced senior to junior contact. Furthermore, lack of common watch standing has removed the opportunity to train while performing other shipboard tasks. Where once work and training could progress simultaneously, now training and work have become independent tasks.

Increased workload has reduced available training time, while increased complexity and introduction of new systems has increased the need for training time.

International registries, lack of manpower and consequent more rapid promotions have reduced the level of experience in senior personnel. Rapid changes in the work environment results in higher turnover and induces highly experienced and skilled personnel to seek employment elsewhere.

From the teacher's point of view the following problems come to mind:

Motivation to train is reduced when there is low crew stability. Why bother training somebody if that person will not return to the ship anyway? Why train somebody if one can do a certain job oneself quicker? This is especially true if the job has relatively low recurrence on a particular tour anyway (such as shore side discharge of slops). Motivation to train is low when one does not really develop a relationship with crew members who are not of the same nationality or culture. Motivation to train is low when one is overworked and tired. Motivation to train is low when one has to train in a language that is not one's native language, and when one has to train an individual whose understanding of your language is low. Motivation to train is low when one has only limited knowledge of the system that requires training. Motivation to train is low when training has to proceed in a forced setting. Training with a beer in one's hand is fun, while training that interrupts a movie is a nuisance.

From the learner's points of view one can almost repeat the same arguments:

Motivation to learn is low when one is faced with having to train on a different system on the next voyage and ship anyway. Motivation to learn is low when one cannot aspire to the next level, since it will not have a higher level of job satisfaction. Motivation to learn is low when one does not feel that the training will provide you with higher control of your work environment but rather will simply pile up more unpleasant tasks that do not seem to benefit you or your shipmates or even your company. Most of all, motivation to learn is low when learning is not related to increasing decision making skills, but rather is related to memorization of endless procedures, directives and regulatory requirements. Motivation to learn is also low when training has to proceed in a forced setting.

The lack of motivation by both the teacher and learner is an incredibly destructive disconnect. It can only be solved by improving the motivations of both the teacher and the learner. And that needs to be solved simultaneously! If one considers that most people aboard ships are both the teachers and learners one can conclude that training is a complex and subtle problem.

Training skills are a rare asset. Only a small fraction of skillful people are naturally able to teach, and to a large extent teaching needs to be taught. This author has been surprised in more than a few recent situations that senior ship officers absolutely have no concept of their duty to train their staff. Somehow, possibly as a combined effect of the above factors, officers are advancing in grade, but no longer acquire the skills to impart their knowledge on junior staff. Possibly, today with the myriad of manuals, regulations and self study aids aboard ships, senior staff is starting to assume that shipboard knowledge comes from a book, rather than from them.

And finally, after having struggled through this endless paper so far and having experienced the limits of communication effectiveness, one has to consider communication skills in training. Communication is not just speaking the same language, which, today, is rare aboard ships, but is also related to having the same interpretive standards. One does not have to spend a lot of time in foreign cultures to realize that the English response "yes", even with the best intentions, can mean any of the following depending on a person's culture, status, and knowledge of the English language:

- I understand what you mean
- I will do what you state from now
- I acknowledge your command, but will ignore it
- I hear a sound but have no clue what you are saying
- I acknowledge that I heard a sound
- I hate your mother and father, your religion, your attitude and your position aboard this vessel and will not waste an opportunity to push you down the tallest stairs I can find.

There have been some innovative efforts at dealing with the cultural disconnects in communications. One such effort is a course named "Dealing with the Dutch" that has been specifically designed to enable Philippine crew

members to function effectively aboard ships with a Dutch culture, and is regularly taught at ROC Nova College in IJmuiden, the Netherlands (Ref: "Schip en Werf").

Of all the domains it appears that the training domain, and particularly the shipboard training domain, faces the most significant problems. However, this also means that even modest improvements in this domain could return significant gains.

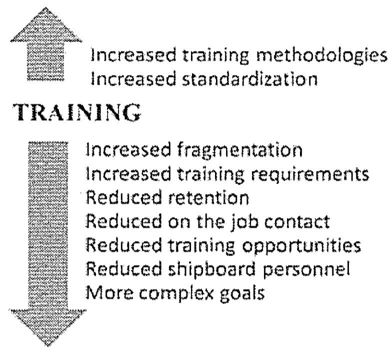

Figure 9. Changes in training methods

4. What Does the Analysis Show?

In simplest terms the analysis is indicating that while there have been significant improvements in safety, occupational health and survivability domains, there are significant concerns that have developed in the other domains.

These concerns have been largely driven by the introduction of subsystems that address efforts to reduce the ship system's environmental impact (environmental survivability).

These new subsystems have increased manpower needs, reduced habitability, increased demand on high skill personnel, increased personnel stress, and increased the need for training.

While there are various indications that the Human-System integration of today's ship system is under stress, it appears that the most direct consequence is the emerging lack of suitable personnel entering the workforce, and probably a lack of retention of fully or partially trained personnel, due to already excessively high ship system workloads.

For the system to remain successful, the manpower issue needs to be resolved. The analysis indicates that the best available domains to exercise for improvements are training, habitability, and further human factors engineering of the sub systems that have been added to ships in recent years.

5. A Possible Solution

A classic truism in design states that a good design is strong in all components of the design spiral, a functional design might be strong in some components, but can never fail in any one component, and a brilliant design is a design that derives mutual benefits from multiple components in the design spiral. This can be expressed as "form follows function", or "weight reductions benefit all systems". What it means is that if one design change can positively affect multiple design domains the design will improve very efficiently.

Human System Integration design functions in the same way. As such, it is beneficial to examine changes that will result in improvements in multiple domains. For example, if one can improve training, but also make training enjoyable, one will improve both training and habitability. For example, if one can improve training by simultaneously performing other manpower tasks and make training enjoyable one can improve the manpower domain, the training domain and the habitability domain.

On the other hand if one increases training, but in doing so increases manpower requirements, there might not be a net gain.

As such, there is a benefit in developing a highly integrated approach in increasing the Human System Integration efficiency of the ship system.

The following design aims to take advantage of this approach. It proposes a modest increase in manpower requirements, but aims to significantly increase habitability, personnel training, and manpower efficiencies. The proposed design focuses on redesign of the shipboard crew structure and on increased integration with shore based resources.

Today ship's crews consist of a deck department, and an engine department. However, today, a third major duty, management and operation of environmental systems, is shared by both departments.

Today the tasks associated with management and operation of environmental systems will easily fill one person's work day. While some tasks, such as bilge water treatment, appear to be more engine department related, other tasks such as garbage management or bilge water exchange have generally been more heavily associated with the deck department. In actual fact neither the deck department nor the engine department will see environmental tasks as their primary duty and consequently will tend to pay less attention to these tasks than reasonably required. From a technical point of view, the environmental systems are not specifically included in either training regimen and, as such, will require specific training that will be in addition to standard deck or engine education.

In passenger shipping there is a general trend to include an environmental officer in the ship's staff. This officer generally functions somewhere at the chief or second mate level, and tends to be a deck officer, but could also be a retrained radio officer or an industrial hygienist.

He generally reports to the Master, and generally does not have any significant contact with the engine room staff. There has not been much evaluation of the role of the environmental officer aboard passenger ships, but based on this author's contact with this position, it often

has the appearance of a dead end position. This is counterproductive since while there should be a shipboard department that has the environment as its primary focus, its effect should reach into the entire ship's staff. In actual fact, the environmental department should function similarly to the other ship departments; it should have a specific structure and responsibilities. This is a reasonable proposition similar to the formation of the engine department when ships were fitted with propulsion engines, and radio officers when ships were fitted with radio equipment.

At the same time it would also be beneficial if all officers take a tour of duty as environmental officer at some stage in their career track in order to gain a solid understanding of the vital nature of the function.

Figure 10 shows a ship staff that incorporates an environmental officer and shows a specific path for shipboard officer advancement. This arrangement also shows a shore tour for all officers and details regarding this position will be discussed later.

The diagram shows that the environmental tasks and systems will be associated with a specific officer's position just like other specific shipboard tasks and systems such as navigation (2nd mate) cargo (chief mate), main engine (1st assistant engineer) and auxiliary engine room systems (2nd assistant engineer).

The environmental officer will not stand watches like the other officers, and, as such, will have greater freedom to interact with the other officers as he circulates around the vessel to perform his various tasks. Additionally the environmental officer will interact directly with the master and the chief engineer, but will actually report to the RP in the ship management office. This removes a specific reporting and responsibility burden from the vessel Master and Chief Engineer and will provide them with much needed time to focus on other tasks.

From a regulatory and law enforcement point of view, the oversight and possible prosecution of environmental regulations can be significantly simplified if a vessel has an environmental department. Environmental inspections and their possible deficiencies will become entirely the responsibility of the environmental officer rather than a shared and confused responsibility for the deck and engine department.

The inclusion of a shipboard environmental officer on the ship's staff will result in a significant enhancement in shipboard communications which inherently improves habitability and training opportunities. Furthermore, environmental officer experience will be a prerequisite for either promotion to master or chief engineer and will be an officer's first opportunity at independent command within the ship structure. Only those officers who have been evaluated to be successful in fulfilling the duties associated with this independent department will be able to advance to the most senior positions.

Figure 10 also shows a shore duty period. Due to the above described changes in ship operations in the last decades, the relationship between ship and shore staff has changed significantly. There was a time when ship and shore staff could pretty much function independently except for contact with port engineers and port captains when the vessel was in port. Today this relationship has changed where ship and shore have become heavily interdependent. While shore staff still tends to be heavily composed of ex-seafarers, there are often significant communication difficulties between ship and shore. This is to a large extent related to simple lack of understanding of each other's tasks and duties, and a certain level of distrust (Ref: Pickles).

The shore duty period is intended to alleviate this system weakness. The environmental officer will need to have a certain level of training prior to being able to take the position aboard the vessel. The shore duty period will provide the opportunity for this training, but will also allow a junior ship officer to get a better understanding of shore operations. This higher level of understanding will result in higher communication efficiencies between ship and shore and reduced stress for all parties. In addition this tour of duty will enhance the status of the shipboard officer and will allow a progressive ship operator to evaluate their officers in shore based activities and will provide the ship operator with a pool of potential shore based employees. If the operator and ship officers have different working languages, this tour of duty will allow the officer to enhance his language skills. During this shore tour the environmental officer in training will become familiar with the ship's operational manuals, VRP's, SOPEPs and other regulatory documentation and make updates as needed and confirm the updates with the ship's active environmental officer. He will also meet and work with the RP and other vital shore support staff.

Taking into account that often there are different nationalities and cultures in the operator's office, the shore duty tour will enable the type of cultural exchange that is so often lacking in today's shipping industry. This type of exchange will also enhance the cultural status of a ship officer and as such will enhance the attractiveness of shipboard positions.

While the implementation of the environmental department aboard ship is rather straight forward from a logistical point of view, the implementation of the shore based tour of duty could be somewhat more complex. The shore tour removes the "work and learn aboard" component and as such is inherently less attractive to an operator. Only progressive operators will be able to generate the energy and foresight that would make the shore tour a truly worthwhile experience.

Some operators might argue that it would be impossible or very difficult to get work permits for the shore duty tour. While this could be true in theory, in effect the shore duty tour is a training position and most countries allow training visas and permits.

Logistically the shore based position is not particularly difficult or expensive to implement taking into account that, from a ship's officer's point of view, there is no difference between being separated from friends and

family in a shore position or in a shipboard position. As such, an operator that runs a modest number of ships can secure a small apartment near the operator's office that is used by the environmental officers in training on a rotating basis.

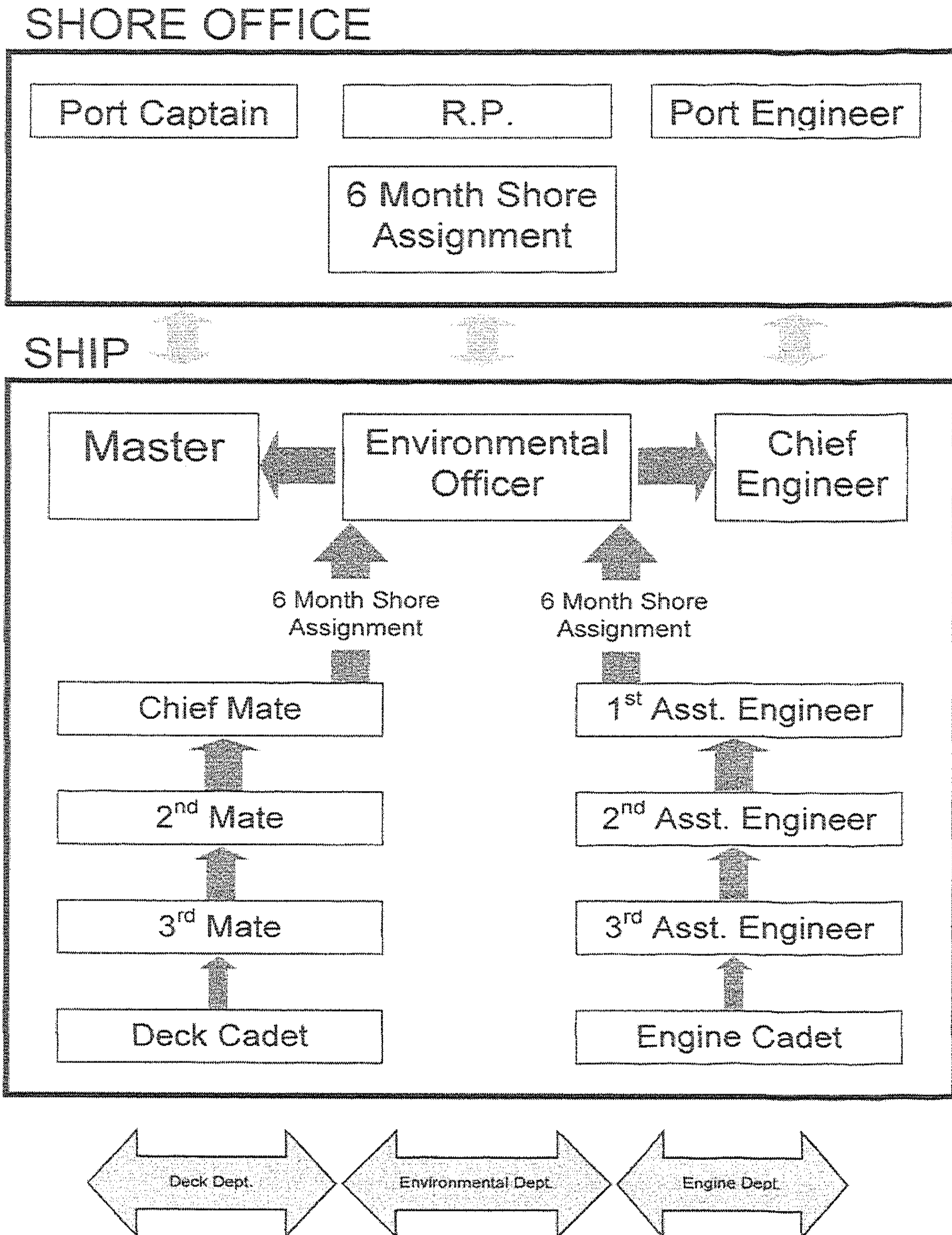

Figure 10. Suggested improved path for shipboard officer advancement

6. A More Formal HSI Approach to Develop and Validate Solutions

Section 5 above provides a possible solution to the trends identified in this paper. This solution is based on valid design philosophy, but is not directly supported by data from any HSI analysis. Undoubtedly it would be worthwhile to perform a more formal HSI analyses that relies on actual metrics. This section provides an outline for such an analysis that is based on an earlier analysis that was performed by the US Navy.

The U.S. Naval Sea Systems Command (NAVSEA) performed an HSI study to assess crew workloads and reduce manpower within the HSI Top Down Requirements Analysis (TDRA). The TDRA process essentially entails modeling of crew tasks associated with representative operational scenarios, estimating time to conduct tasks, describing workload as percent time busy on tasks, defining the manpower requirement for fulfilling this workload, and developing approaches to workload (and manpower) reduction for task sequences that are labor intensive. The NAVSEA HSI TDRA process has been primarily used for new ship acquisition programs, but is equally applicable for existing ship manpower reduction and evaluations.

The HSI TDRA approach was applied to manpower reduction for new Military Sealift Command Fast Sealift ships, which are somewhat comparable with commercial ships in manpower structure. Beginning with a crew of 45, the HSI analysis resulted in three options for crew reduction, resulting in crews of 12, 16 or 21. Each had distinct advantages and disadvantages. It was recommended that owners/agents could determine their individual manning levels based on how these advantages and disadvantages reconciled with their operating policies and conditions (ports, routes, unions, etc.). The greatest technical risks existed for the 12 person crew:

- The major technical risks to achieving this level were maintenance requirements and equipment reliability. Operationally, a crew size of 12 is low risk.
- Manning levels were programmed to increase 1 to 2 as ship ages and reliability declines.
- Workload analysis and simulations indicate very high workload for off-normal conditions, such as fire fighting.
- Damage control capability was limited (e.g., forming hose teams).
- Watchstander incapacitation will require two bridge watches (6 on and 6 off), leading to potential for fatigue.
- Little "surge" capacity of the crew was available to meet special conditions, such as maintaining surveillance.

The options also allowed for dynamic manning based on temporal and other considerations. For example, a manning level of 12 for an easy route (few ports of call in fair weather) and 16 for a difficult route (during adverse weather to many ports that have difficult entry).

The application of the HSI TDRA methodology to commercial shipping under all of the environmental and administrative constraints described above is essentially a three step process.

Step 1: quantify crew workloads under the present manning configurations for selected representative and worst-case scenarios. These scenarios would be few in number but would include conditions and requirements that would be challenging for workload, human performance and safety of the crew. This step would require identifying the tasks performed by individual crewmembers throughout each scenario (including all on duty tasks as well as all administrative, environmental, supervisory and training tasks), and estimating the time needed to accomplish each task. By virtue of the task networks developed for the scenario, task network simulations would be conducted using an event simulation capability which would exercise the task network, tally the times on task for each crewmember while on duty, and provide an estimate of the workload of each crewmember, defined as percent of time busy conducting tasks. In NAVSEA a workload is considered adequate if the crewman is engaged in task performance for not more than 75% of the time.

Step 2: identify HSI approaches to reduce workload on existing ships. This would involve identifying opportunities in the selected scenarios to:

(a) Automate ship functions to the extent possible given the constraints that this is an existing ship. This could entail some modernization of ship systems by inserting technology that automated functions and tasks previously performed manually. Based on the above trends identification, this could also relate to automation of reporting tasks rather than automation of equipment.

(b) Consolidate ship functions by reassigning responsibility for task performance to another operator who has less workload at this time.

(c) Eliminate functions by moving activities from the ship to the shore, or by eliminating the need for the function.

(d) Simplify functions and tasks by applying human factors engineering to make the task more intuitive, less complex, performed with greater accuracy, performed with fewer errors, performed in a safer manner, and performed in shorter time.

The task network simulation described in Step 1 would be repeated with changes in the tasking as a result of the changes described above, and the associated workloads would be calculated.

Step 3: Modify the manpower structure as suggested in section 5 above to provide personnel with the responsibility for environmental regulatory and administrative activities (including on-board training and supervision of junior crewmembers), conduct task network simulations, estimate workloads and compare the resultant

workloads with the workloads produced in Step 2. On that basis, select the technique to reduce workloads in existing ships.

This process would validate the need for an environmental department aboard ships or could result in alternative solutions and improvements. It needs to be noted that this is not a trivial research program since solutions would need to be based on actual shipboard observations and would need to be universally, or near universally, applicable within the international commercial maritime community. Therefore a large amount of data and alternatives would need to be collected and evaluated before an optimal solution can be identified.

In addition to the above first principles approach this author also suggests that a thorough review of the technical discourse on manning of the early eighties be made. Undoubtedly there will be valuable suggestions and methods that apply to today's situation.

7. Conclusions

The proposed change in manning structure is based on a rather exhaustive overall HSI review of the ship system. This review shows that HSI has not kept up with recent ship system changes. The proposed crew structure modification addresses the weaknesses identified in the system by modestly increasing the manpower aboard the vessel, and by enhancing personnel, habitability, training and communication efficiencies.

However, the shipping community tends to be highly competitive and a ship operator generally does not act unilaterally as far as increased investment in manning is concerned.

As such it is recommended that the environmental department be made a mandatory shipboard department through the International Maritime Organization. It is interesting to note that this would be the first IMO regulatory change in a very long list of recent IMO regulatory changes that will address the needs of shipboard crews rather than the public.

Undoubtedly the above proposal will require further refinement and evaluation. This author is very much interested in any comments and suggestions related to this subject. While the HSI problems noted in this paper are real, there could quite reasonably be other more effective and efficient solutions to today's manning problems.

The next level of evaluation of this proposed ship system change would be related to further investigations into actual manpower and personnel requirements and task division between the deck, engine and environmental departments as outlined in section 6.

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References

A Future with Adventure, pamphlet, The Ship Operations Cooperative Program, 2005.

Card, James C., Clifford C. Baker, Kevin P. McSweeney and Denise B. McCafferty. "Human Factors in Classification and Certification," 2005, SNAME Annual meeting..

"Checklist for Considering Human Element Issues by IMO Bodies," International Maritime Organization, 22 May 2006. MSC-MEPC.7/Circ.1.

Dolan, Nancy and Jennifer McGovern Narkevicius, PhD, "Systems Engineering, Acquisition and Personnel Integration (SEAPRINT): Achieving the Promise of Human Systems Integration," NATO, OTAN, 2005.

Folds, Dennis J., Ph.D., "Human Systems Integration," PowerPoint presentation, Electronic Systems Laboratory, Georgia Tech Research Institute, June 2007 http://www.incose.org/practice/techactivities/wg/hsi/docs/Human_Systems_Integration_Seminar_INCOSE_June_2007.pdf.

Gaffney, Michael E., "Effective Manning at American President Lines", American President Lines Report MA-RD-840-89008 to the Maritime Administration, 6 June 1989.

"Guide for Crew Habitability on Ships," American Bureau of Shipping, December 2001.

Hendrikse, Johan, PhD. etal, "Effectively Including Human Factors in the Design of New Facilities" 2nd Annual Workshop on Human Factors in Offshore Operations, Houston, TX, April 2002

"Human Element Assessment Tool for Ships (HEAT–S), Maritime and Coastguard Agency, 2006.

Khandpur, Rajiv, "Human Factors in Ship Design", undated, available through SNAME panel O-38.

Klein, Gary, Sources of Power: How People Make Decisions, The MIT Press, 1999.

Krueger, Gerald P., Ph.D., "Navy Human Systems Integration (HSI): SEAPRINT Program", Slide 11, PowerPoint presentation, Wexford Group Int'l, 20 October 2006, http://www.donhcs.com/hsr/20_october/doc/G.%20Krueger%20presentation%20at%20ASN%20Human%20Sciences%20Research%20Seminar%2020%20Oct%202006.pdf.

Landsburg, Alexander C., Larry Avery, Robert Ceaton,

J. Robert Bost, Carlos Comperatore, Rajiv Khandpur, Thomas B. Malone, Christopher Parker, Stephen Popkin and Thomas B. Sheridan, "The Art of Successfully Applying Human Systems Integration (HSI)," undated, available through SNAME panel O-38.

Lewarn, Barrie, "Challenges for Maritime Educators and Trainers", Seaways 2008.

Malone, Thomas, Pamela Savage-Knepshield and Larry Avery, "Human-Systems Integration: Human Factors in a Systems Context," Human Factors and Ergonomics Society, Bulletin, Volume 50, Number 12, December 2007, pgs. 1-3.

Miller, G.E., "The Human Element and the Maritime, Changing the Mindset" Marine Log Sixth Annual Conference on the Role of the Human Element in Maritime Operations, Washington, D.C., April 2001.

Noyes, Janet M. and Yvonne Masakowski, Decision Making in Complex Environments, Ashgate Publishing, Ltd., Aldershot, UK, 2007.

"Papering Over the Problem", Fairplay 21 Feb. 2008: 1-2.

Pickles, Anneley. "What About Generation-Y?," Shiptalk JOBS, Gangway, Edition 6, December 2007.

Ship Design and Construction, Lamb, Thomas, Editor, The Society of Naval Architects and Marine Engineers, Jersey City, 2003.

"Schip en Werf," May 2007, Article in Dutch language "Course for getting along with Dutchmen" www.novacollege.nl

The Human Element, An Introduction, pamphlet, Lloyd's Register, 2008.

"Weighing the Evidence on ISM", "How Many Inspections Are Really Needed?", "Subject to Scrutiny", Surveyor Winter 2004: 2-14.

Yamanaka, Keiko, and Michael Gaffney, "Effective Manning in the Orient", New York State School of Industrial and Labor Relations, Cornell University, 1988.