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WORK SCHEDULING AND WORKLOAD DISTRIBUTION IN MERCHANT VESSEL OPERATIONS: AN EXAMINATION OF ALTERNATIVE WATCH SYSTEMS

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ABSTRACT

Federal law generally requires that the crew of an American merchant vessel be organized into three watches. The authors review recent trends in vessel manning and suggest that, as a result of these trends, the three-watch system may now be suboptimal in terms of maritime safety. Alternative watch systems are described, and necessary changes to Federal law are discussed.

INTRODUCTION

The operation of merchant ships ordinarily requires 24-hour attention by vessel personnel over extended periods of time. Vessel operations also commonly include dramatic variations in workload intensity, extended duty periods, and adverse environmental conditions. Particularly for certain officers in the deck department (those who are responsible for navigation and control of vessel movements), the fatigue that often results from these conditions and its impact on marine safety are matters of serious concern. Recent trends toward smaller crews aboard merchant ships also create a strong incentive to maximize the utilization of vessel personnel while maintaining or enhancing their job satisfaction. Thus, the job design issue of watch scheduling--that is, the manner in which round-the-clock monitoring and control tasks are assigned to available personnel--merits careful scrutiny.

United States law has required the division of deck and engine departments into watches for most ocean-going merchant vessels since 1915. The three-watch system supplanted the two-watch system which had been common on sailing merchant and naval vessels. One likely rationale for this law is the protection of crew from overwork, so that they will be less fatigued, and more alert, while on watch. Given the application of the two-watch system on sailing vessels during the nineteenth century, the requirement for three watches seemed at the time to be justified on grounds of both safety and crew welfare. However, changes in vessel technology, manning, and operations over the past two decades have reversed this situation. A two-watch system, for mates in particular, may result in safer operation and a more equitable division of labor among the deck officers of the typical U.S. merchant vessel.

BACKGROUND

Economic pressures, technological innovation, and a scarcity of competent and affordable mariners have precipitated significant changes in the size, composition, and organization of crews manning the ships of the world's merchant fleet. In some countries, this has meant radical reduction in manning scales.

It is primarily in the developed maritime nations that the greatest interest in reduced manning has been demonstrated in recent years. Countries with strong maritime labor unions and high maritime personnel wage levels have the most to gain from manning reductions, and are thus most likely to invest the capital necessary to install equipment enabling the use of smaller crews (Mottley, 1989). Crew costs aboard ships flying the flags of the traditional maritime states and those in flag of convenience (FOC) fleets can differ by ratios as great as six to one (Cessna, 1986). Thus, vessel operators using traditional registries have substantial motivation to reduce manning where possible and to extract from remaining personnel the maximum productivity possible.

Changes over time in the size and composition of ship's crews have included the elimination of positions made redundant by technological advances and those service ratings who were formerly responsible for the comfort of the rest of the vessel's crew. In some traditional maritime countries, this has resulted in the reduction of crew size from the high forties to the low teens over the past three decades. The progressive contraction of merchant ship crew size in a representative European fleet is shown in Table 1.

For vessels operating under U.S. flag, reductions have been less dramatic, with older ships, technological handicaps, the influence of maritime

Table 1
Changes in Merchant Ship Complements [European], 1960-1990

15,000 Ton Cargo Liner, 1960

Master

Deck Department	Engine Department	Catering Department
Chief Officer	Chief Engineer	Ch. Steward/Purser
2nd Officer	2nd Engineer	2nd Steward
3rd Officer	3rd Engineer	Chief Cook
4th Officer	4th Engineer	2nd Cook/Baker
2 Deck Cadets	5th Engineer	Butcher
Radio Officer	6th Engineer	3 Stewards
4 Quartermasters	Chief Electrician	2 Catering Boys
Carpenter	2nd Electrician	
Bosun	2 Engine Cadets	
Bosun's Mate	ER Storekeeper	
8 Able Seamen	Donkeyman	
2 Ordinary Seamen	4 Greasers	
2 Boys	2 Boys	Total: 55

30,000 Ton Containership, 1987

Master

Deck Department	Engine Department	Catering Department
Chief Officer	Chief Engineer	Cook
2nd Officer	2nd Engineer	Cook/Steward
3rd Officer	3rd Engineer	
Radio/Elec. Officer	6 GP Ratings	Total: 16

30,000 Ton Containership, 1990

Master
Chief Watchkeeper (Deck or ER)
2nd Watchkeeper (Deck or ER)
3rd Watchkeeper (Communications)
Electronics Specialist
4 Mechanics
Cook Total: 10

Source: Michael Grey, "Manning the Merchant Ship," *Seascape*, Sept. 1987: 5.

labor unions, and regulatory constraints combining to keep crew sizes for oceangoing ships generally above eighteen (for discussion of regulatory issues in this context see Helmick & Glaskowsky, 1994).

Organizational innovations that have occurred in the onboard work environment include democratization of the workplace, attempts to soften the rigid delimitation between officers and ratings, efforts to reduce specialization of labor functions, and endeavors to increase stability of employment. Generally, the nations of Northern Europe and Japan have been in the forefront of developments in this area.

Advances in the area of automation affecting, or potentially affecting, ship manning include innovations related to navigation, management, communications, mechanical, and maintenance functions. Rapid strides have been made in the application of sophisticated technology to the operational needs of commercial ships. Examples include the Global Positioning System (GPS), the Global Maritime Distress and Safety System (GMDSS), integrated bridge designs, expert (artificial intelligence) systems, the Electronic Chart Display Information System (ECDIS), remote-controlled winches, computerized

planned-maintenance programs, low-maintenance machinery, and modular equipment design, to name a few. However, there are many ships in service that operate without benefit of such leading-edge equipment.

Technology notwithstanding, one possible consequence of reduced manning is increased fatigue among vessel personnel who have to assume the burden of responsibilities formerly borne by other crew members. Fatigue plays a significant role in many human factors-related accidents (Connaughton, 1988; Pettin, 1987; "Safety," 1993). Fatigue and inadequate sleep have known negative effects on human performance, as has been best documented by aviation human factors studies. These effects can be summarized as: (1) increased reaction time, (2) reduced attention, (3) diminished memory, and (4) mood alteration--in particular, withdrawal (Graeber, 1988). Assuming similar impacts on maritime personnel, the need to ensure that the workload and duty schedules of individual watchkeepers are carefully planned and monitored in order to prevent a deleterious effect on merchant vessel safety is clear.

Modern ships are demonstrably more dependent for their safety on the personnel who operate them than on any other single element. Merchant vessel casualties are overwhelmingly the result of human error (Millar, 1980; "Safety," 1993; Unsworth, 1987). A recent report generated by the U.S. Coast Guard as part of its effort to address the problem of human error in merchant marine safety concluded that this cause accounts for between 75 and 96 percent of marine casualties. The report also identified the three most prominent specific human-error problems as fatigue, inadequate coordination between pilots and bridge crews, and inadequate technical knowledge (especially of radar). These causes were found to affect all segments of the maritime industry (U.S. Coast Guard, 1995).

The consequences of merchant vessel casualties are sobering. Between 1982 and 1994, global merchant vessel losses ranged between .8 million and 1.7 million gross tons per year. Although there is wide variation in the number of ships lost from year to year, an average of 141 vessels of over 500 gross tons were lost each year during this period (Magnier, 1995; "Safety," 1993). Deaths at sea resulting from total and partial losses to ships in this category numbered 1,478 in 1994, compared with 615 lives lost in 1993 (Magnier, 1995). If smaller vessels were included in these statistics the numbers would be substantially higher, but reliable data concerning such casualties are not available.

Given increasing awareness of the magnitude of the human error problem in marine safety, and mounting evidence that fatigue is either a primary or secondary cause of many casualties, an examination of the manner in which shipboard workloads are distributed among vessel personnel--especially with respect to hours of work and watch scheduling--is called for. The next section provides some historical background in this context.

THE TRADITIONAL TWO-WATCH SYSTEM

Crews of American merchant vessels during the age of sail were almost invariably divided into two watches, with the exception of non-watchstanding "idlers" (cooks and skilled ratings such as sailmaker and carpenter). Officers were the master and one or two mates. On a vessel with only one mate, the master was in charge of one watch; otherwise a mate commanded each watch. Although a clipper ship of 1500 tons might have a crew of fifty to sixty, the more typical American sailing merchant ship was a brig or topsail schooner of between 500 and 750 tons, manned by as few as 12 men (master, mate, bosun/sailmaker, eight sailors, and a cook/steward).

Four-hour watches were the most common arrangement, often "dogged" with the daily interposition of 2 two-hour watches so that no one stood the same watch day after day. Although watch arrangements varied, a typical watch arrangement is shown in Table 2 (Brown & Brown, 1961).

Table 2
A Two-Watch System on Sailing Merchant Vessels

0000-0400	"Midwatch"
0400-0800	"Morning Watch"
0800-1200	"Forenoon Watch"
1200-1600	"Afternoon Watch"
1600-1800	"First Dog Watch"
1800-2000	"Second Dog Watch"
2000-2400	"Evening Watch"

THE THREE-WATCH SYSTEM AS REQUIRED BY U.S. LAW

In 1915, the division of engine personnel into three watches was mandated by Title 46 USC, Section 8104 (d). The statute was amended in 1936 to cover licensed officers, convert sailors to the three-watch system, and add coal passers:

> *On a merchant vessel of more than 100 gross tons. . .the licensed individuals,*

> *sailors, coal passers, firemen, oilers, and water tenders shall be divided, when at sea, into at least 3 watches, and shall be kept on duty successively to perform ordinary work incident to the operation and management of the vessel.*

The same section also requires that no one in the deck or engine departments, whether licensed or unlicensed, may be required to work more than eight hours in one day. However, courts have held that the existence of a collective bargaining agreement specifying overtime standards makes overtime work within those standards voluntary (National Research Council, 1990).

Ocean-going merchant vessels of greater than 1,000 gross tons are required by the same title to have a licensed master and three licensed mates (unless on a voyage of less than 400 miles, in which case only two mates are required). However, collective bargaining agreements for deck officers on U.S.-flag ships during the period 1945-1975 almost invariably called for four mates. (Exceptions to this rule included some coastal tankers, and the numerous Liberty-class freighters). A combination of factors in the mid-1970's motivated vessel operators to negotiate with the officer unions a reduction of deck officers from four to three on virtually all U.S.-flag oceangoing merchant vessels. Some of these factors were: the drastic rise in fuel prices that followed the Yom Kippur War of 1973, a more parsimonious policy on the part of the Maritime Administration in the calculation of that portion of the Operating Differential Subsidy attributable to wage variances between American ships and their foreign competitors, intensified competition, and the general international trend toward reduced manning.

The senior deck officer is the chief mate, and he/she has traditionally borne significantly greater responsibility than the other ship's officers. For this reason, on large ocean-going vessels with four mates, the chief mate typically did not stand a watch, and the fourth deck officer was an additional third mate. The chief mate devoted full time to his two main responsibilities of cargo operations and deck/hull maintenance, while the second mate stood the 4-to-8 watch (morning and evening), the third mate the 12-to-4 watch, and the junior (or "number two") third mate the 8-to-12 watch. This arrangement minimized the overtime requirements of the watch-standing officers, allowing them to be well-rested (at least in theory) at the commencement of each watch at sea.

The disappearance of the extra third mate caused the return of the chief mate to the watch bill. The most common arrangement on three-mate ships is one in which the chief mate stands the 4-to-8 watch, the second mate the 12-to-4, and the third mate the 8-to-12. The chief mate has not, however, been relieved of responsibility for cargo operations and maintenance. In fact, trends in vessel operations and manning have generally made these responsibilities more demanding. Round-the-clock cargo operations, for example, coupled with the usual requirement by masters and owners that the chief mate be on duty whenever cargo is being worked, combine to make marathon work turns of 24 or 36 hours not uncommon. Supervision of cargo activities is physically demanding, requiring frequent movement about the vessel and in and out of cargo holds and tanks. When the last four hours of such a workday consist of standing a bridge watch while the vessel gets underway and maneuvers out of port, serious safety issues arise from the possible impact of fatigue on decision-making ability (National Research Council, 1990, p. 39; Williams, 1992).

Nor can the chief mate rely on the at-sea portion of the voyage to recuperate. Still responsible for cargo operations and maintenance of hull and deck, he or she must usually spend most of the daylight hours between watches supervising sailors as they do such work as painting or servicing cargo gear. Reduced manning has placed greater demands on the chief mate in the form of a reduced deck force. The loss of a non-watchstanding bosun (deck petty officer), in particular, means the mate must spend more time in direct supervision of maintenance work. Cargo responsibilities also continue, with such activities as tank cleaning; daily checking of refrigerated cargo temperatures, containers, or liquid cargo; overseeing and checking lashing and securing of cargo for sea; and planning discharge and stowage for the next port. As head of the deck department, the chief mate is also usually responsible for discipline, keeping records of crew overtime, and often, such miscellaneous but essential chores as sounding ballast tanks.

The result of these changes is a work day of at least sixteen hours. As a practical matter, the chief mate has no more than about seven hours per day (and often less) for sleep, recreation, shore liberty, calling or writing home, and taking care of personal needs such as laundry. Quite aside from the impact of such a schedule on the morale and welfare of the officer concerned, the safety implications are serious. As noted above, merchant vessel casualties are due in large part to human error, and excessive fatigue is one cause of error. In addition to fatigue, another possible source of distraction is the (illegal but often irresistible)

temptation for the chief mate to catch up on his or her paperwork while on bridge watch at sea (Williams, 1992). Anecdotal evidence suggests that such practices are often consistent with the expectations of vessel managers.

The duties of the subordinate mates have generally not increased proportionately to those of the chief mate, creating an imbalance in the workloads required of the three officers. For example, the second mate is traditionally the vessel's navigation officer, and once spent considerable off-watch time in voyage planning, correcting and updating charts and navigational publications, maintaining navigational instruments and gear, and fixing the ship's position by celestial observation. Computers, the transfer of the routine and clerical portions of these tasks from ship to shore, and modern electronic navigation systems have--in some ships--reduced the time required for these activities.

Perhaps operational safety would be enhanced, and workloads among deck officers more evenly distributed, by once again relieving the chief mate of watchstanding duties, and dividing watchstanding responsibilities between the two junior deck officers. Such a system would offer multiple advantages: (1) at sea, each bridge watch would be stood by an officer potentially less fatigued and less distracted by other duties than at present; (2) in port, the chief mate would be relieved of routine in-port watchkeeping duties; and (3) the junior officers would bear a more equal share of the workload while relieving the chief mate of undue stress and fatigue.

The major potential disadvantage would be an increase in fatigue for the second and third mate due to longer hours spent on watch. It should be stressed that a return to the traditional two-watch system based on four-hour watches is *not* advocated; this would be a step backward, even if the duties of the officers were confined to watchstanding. However, it may be possible to devise a two-watch system that is superior to both the present system and the one it supplanted.

POSSIBLE TWO-WATCH SYSTEMS FOR DECK OFFICERS

Ruling out watches shorter than two hours and watches of an odd number of hours as impractical, the alternatives for a two-watch system for merchant vessels are eight in number: 4, 6, 8, or 12-hour watches, dogged or not dogged. In each case, officers would have the opportunity of 12 hours rest and personal time, on average, out of each 24-hour period. The traditional four-hour watches, however, allow for insufficient uninterrupted rest on a two-watch system, and are therefore not recommended. Watch systems of 6, 8, and 12 hours, either dogged or not dogged, all have advantages and disadvantages.

Six-hour watch systems (see Figure 1) allow somewhat less than six hours of uninterrupted rest between watches, but keep watches relatively short, thus minimizing both boredom and fatigue. The dogged version allows for watch rotation, while offering more opportunity for social interaction with the rest of the crew during the day. It has the disadvantage of requiring nine hours of duty for one officer and fifteen hours for the other each calendar day. But so long as the same watch system continues uninterrupted, both in port and at sea, each officer will average 12 hours on and 12 hours off.

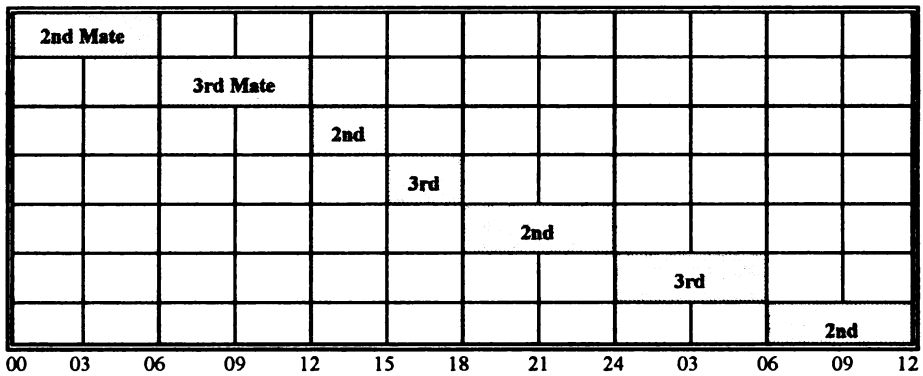
It should be noted that the principal advantage of watch rotation with any two-watch system is that it provides each officer with an opportunity for night sleep on alternate calendar days. This may partially alleviate the disturbance to the normal circadian sleep-waking cycle caused by any watch system including night watches, which is inescapable on a vessel underway around the clock. The present three-watch system has been found to disrupt circadian rhythms of crew members and to deprive them of sleep (Low, Goethe, Rutenfranz, & Colquhoun, 1987). This is also held to be a disadvantage of a six on and six off two-watch system (Pollard, Sussman, & Stearns, 1990).

In a reversal of the six-hour systems, the undogged version of the eight-hour systems results in unequal duty hours during each calendar day but allows the watches to rotate, while the dogged version equalizes duty hours but provides no watch rotation (see Figure 2). Eight-hour watches offer the advantage of nearly eight hours of night sleep for each officer, but eight hours on watch could be excessively fatiguing.

Twelve-hour watches (see Figure 3) represent the extremes of the advantages and disadvantages noted for the other systems. The undogged 12-hour watch system has been recommended as a result of research into sleep disruption caused by the present three-watch system (Fletcher, Colquhoun, Knauth, DeVol, & Plett, 1988). Under such a system, while officers would have, on average, nearly 12 hours for rest and personal time out of each 24, 12-hour watches could be very fatiguing. Either through boredom or stress, depending upon the circumstances encountered during a particular interval, the watch officer's concentration could lessen, and his or her decision-making ability could diminish. This system may be acceptable under certain conditions, such as the at-sea portions of long transoceanic passages on relatively slow ships. The dogged version of the

Figure 1
Two-Watch Systems with Six-Hour Watches

DOGGED WATCHES



WATCHES NOT DOGGED

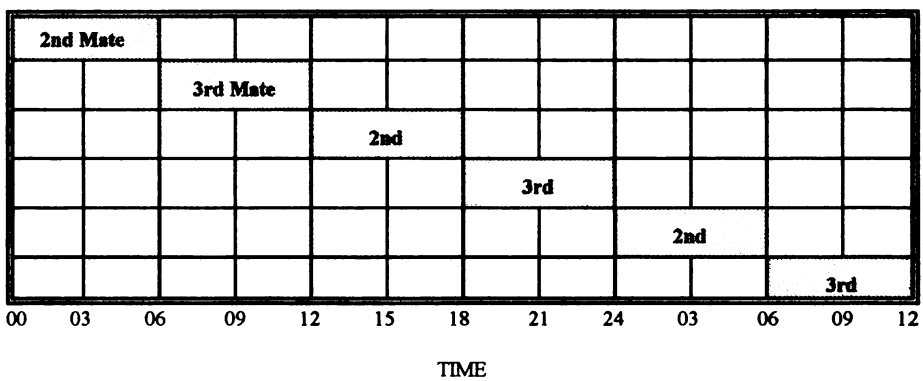
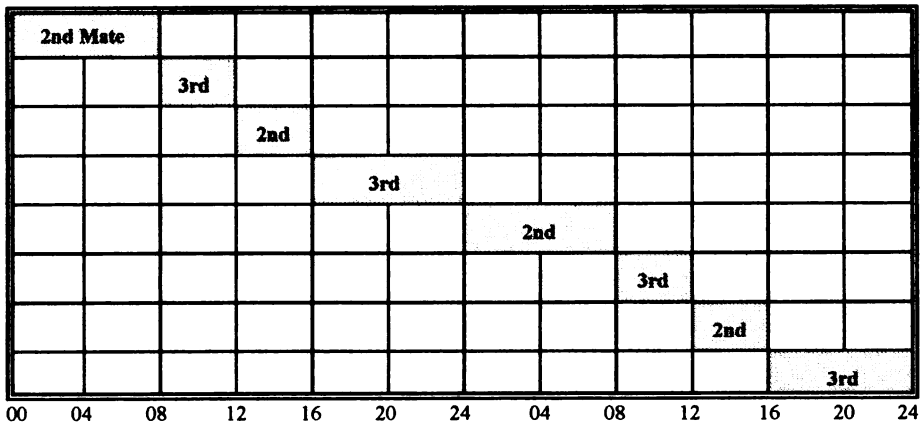


Figure 2
Two-Watch Systems with Eight-Hour Watches

DOGGED WATCHES



WATCHES NOT DOGGED

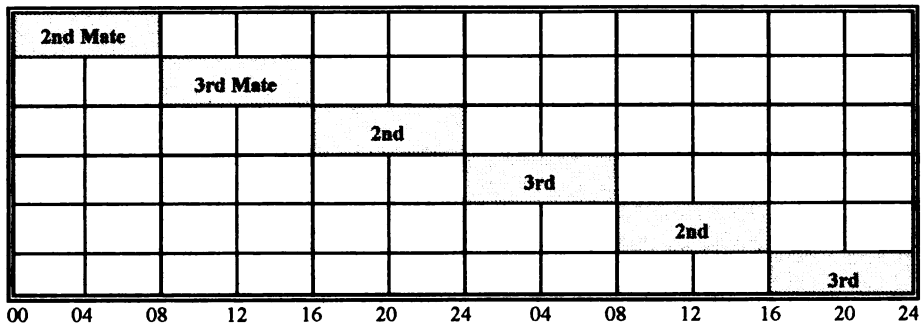
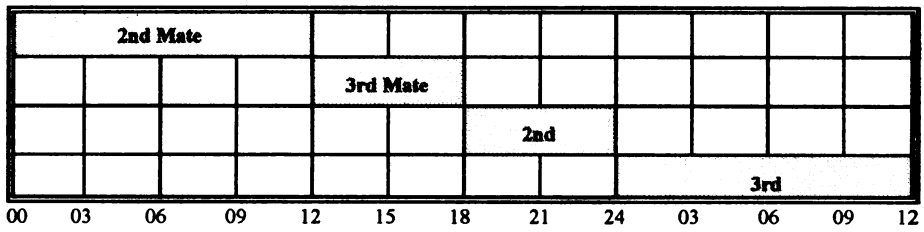
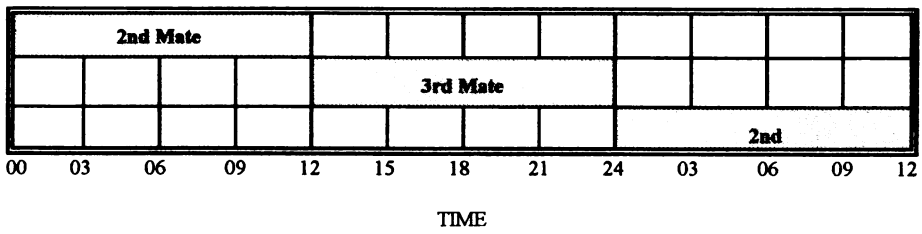


Figure 3
Two-Watch Systems with Twelve-Hour Watches

WATCHES NOT DOGGED



WATCHES NOT DOGGED



12-hour watch system, shown in Figure 3 for the sake of completeness only, would be unacceptable under any conditions, as it would require 18 hours duty out of 24 every other day. Its only advantage is watch rotation.

THE OPTIMAL SYSTEM?

None of these systems is ideal for all vessels under all circumstances. The dogged, eight-hour system depicted in Figure 2 may be optimal for many ships under normal operating conditions. Officers would stand the same watches each calendar day, as in the present system, and would have one off-duty period each day of eight hours duration, much of which would be during hours of darkness. In addition, each mate would have a four-hour off-watch period during daylight hours, allowing time for collateral duties, social contact with other crew members, recreation, taking care of personal needs, or more sleep. Finally, the alternation of eight-hour with four-hour watches would add variety to the work day, thus perhaps helping to alleviate boredom and stress.

One disadvantage of this system is the lack of watch rotation; another is the fact that it allows for a maximum of only eight hours of uninterrupted rest. These are also features of the current three-watch system.

ANOTHER ALTERNATIVE TO THE THREE-WATCH SYSTEM

An alternative solution to the problem of the overstressed chief mate is the assumption of a watch by the master. There is precedent for this historically, as noted above, and on vessels of under 1,000 gross tons. It might be argued that such an arrangement would not add materially to the master's workload, as his/her presence is required anyway. It should also be noted that the master is presently free to relieve any deck watch officer if the safety of the ship so dictates–as when, for example, a mate has had insufficient rest to stand his watch safely. However, there are at least two serious objections to this approach:

1. The master is legally in charge of, and responsible for, the entire vessel and all aspects of its management, not merely its navigation. While in charge of a bridge watch, he/she would be confined to the bridge, and possibly constrained in the performance of other responsibilities.

2. Both custom and interpretations of relevant law are often cited as requiring the presence of both the master and the watch officer on the bridge under certain conditions, such as when maneuvering in heavy traffic, in restricted waters, in restricted visibility, or in the presence of ice. It is the master's responsibility to anticipate this need and to be as fresh and rested as possible when his/her presence is required. A requirement to stand routine bridge watches would interfere with this responsibility.

Nonetheless, there may be situations in which the master would, at his/her discretion, stand one or more watches in place of one of the mates.

CONCLUSIONS AND RECOMMENDATIONS

A change to a two-watch system would require a change in relevant Federal law. The requirement in Title 46 of the U.S. Code for a three-watch system is widely regarded as inflexible and unsuited to present-day conditions, for both deck and engine operations, and is overdue for revision (National Research Council, 1990). However, the requirement for a licensed master and *three* licensed mates should be retained. In place of the present rigid requirement for a particular watch system, masters should be allowed to organize their crews into watches in the manner best suited to the operations of the vessels they command.

This change necessitates at least one other: the creation of effective statutory limitations on the number of hours merchant vessel personnel are required to work, and the imposition of legally mandated minimum hours of rest. Such work-hour limitations currently exist under U.S. law for tank vessel personnel only (deriving from the Oil Pollution Act of 1990). However, restrictions on hours of work and similar matters related to fitness for duty are currently being addressed on the international level by amendments to the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 1978 (STCW). The United States is signatory to this convention.

For U.S.-flag merchant vessels, reduced manning and the legal requirement for a three-watch system may combine to create a less-than-optimal operating environment. Further exploration of alternative watchkeeping arrangements and careful analysis of the safety ramifications of such systems are clearly necessary.

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