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Introduction to an Innovative Crew Composition Approach Based on Safety/Operational and Financial Requirements

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Abstract

This paper proposes a tool to estimate crew composition based on safety/operational and financial requirements. As there is a tendency of ship owners to implement improved technologies on board their vessels, there is no systematic way to predict their potential effect on crew size and composition (typically determined by flag state authorities on a case-to-case basis) nor on the type and complexity of on board duties new technologies might dictate. The main aim of this paper is to develop a tool to assist in determining crew composition, by taking into account both administration's and the ship owner's point of view. Based on data collected from ship owners, a data mining technique is implemented in order to form a generalized framework that estimates crew composition as a function of ship type, size, and degree of automation. The agreement of model predictions with records from specific (vessel) cases is very good in terms of safety (for operations such as watchkeeping, mooring/unmooring, loading/unloading). The specific intended use of this tool is to help a ship owner decide whether it is cost-beneficial to retrofit a conventional vessel with advanced technologies that would potentially entail a reduced crew (probably dealing with different and more complex on board duties). Its main benefits are that it can be used to estimate crew composition before any vessel construction or upgrade has actually taken place and that it allows crew composition to be easily adapted to the technological evolution of ship systems even at their current rapid pace.

Key words: crew composition, manning, classification tree, data mining

1 Introduction and Background

The maritime community and its stakeholders have been affected by the recorded technological advancement in numerous ways; namely by implementing state-of-the-art means of manufacturing or adopting improved operational procedures and methods. The introduction of much automation to vessels has led to a substantial change of the duties carried out by certain crew members. For example, the installation of sophisticated integrated bridge control systems has altered bridge and engine officers' watchkeeping obligations into more structured and technology dependent procedures. Hence, an up-to-date outline of the tasks needed to maintain and operate a ship leads necessarily to the requirement for enhanced crew skills and capabilities, improved or novel safety-oriented shipping culture and allows possibly a reduction in manning.

The work described in this paper was motivated by the requirements of the EU-sponsored research project ATOMOS IV (Advanced Technologies to Optimize Maritime Operational Safety – Intelligent Vessel). This project aimed at promoting safety, efficiency, and competitiveness in waterborne transport by providing a process for retrofit of innovative technologies to the existing fleet (in a cost-effective manner), and by demonstrating it through a case study. A central task within ATOMOS IV was to develop the 'Retrofit Strategy Tool', a tool that can assist ship owners to evaluate the decision whether or not to retrofit their (conventional) vessel with ATOMOS-type advanced technologies. To make such a decision, a cost benefit analysis had to be carried out. As one of the major cost parameters is crew costs, the benefits of crew reduction are clear, if there is rational algorithm that estimates crew composition of the retrofitted vessel (from now on referred to as ATOMOS vessel) as a function of its technology level. In this context, a *crew composition tool* was developed and validated, based on a database covering issues of manning in relation to the automation level assigned to the ship. This paper, then, describes the rationale and methodology that link crew composition and level of automation on vessels based on a functional analysis of the tasks performed by the crew under specific safety related constraints.

It should be emphasized right at the outset that the specific intended use of the tool developed in this paper is rather limited and focused: to help a ship owner decide whether it is cost-beneficial to retrofit a conventional vessel with advanced technologies that would entail a reduced crew. To do so, an estimate of the reduced crew is necessary, and this paper suggests a systematic way of doing so. At the same time, whereas it is certainly not our view to suggest that this tool should replace the existing regulatory framework or practice on crew composition, we also think that the results of this paper are interesting enough so that the tool developed herein, or possible modifications thereof, could assist maritime policy makers in the analysis of manning alternatives for advanced technology vessels.

Specifically for crew composition, its determination has always been a decision based on the respective flag state rules and guidelines. The aforementioned rules and regulations are generally flag-specific. Almost all flag states divide the vessel crew into two main categories: deck crew and engine crew. The determination of deck crew size usually depends on vessel GRT, while the determination of engine crew size is usually based on main engine power; there are certainly cases that these are calculated in a different way, i.e. both engine and deck crew may be determined according to vessel size (GRT). The crew size derived from flag state administrations can be characterized as the minimum required for the safe operation of vessels.

It is noted that in general, the standing principles of safe manning incorporate issues of safe operation, ship security, protection of the marine environment and emergency procedures; more specifically, the determination of vessel manning should accommodate[1,2]:

1 IMO: *Principles of Safe Manning*. A.890(21), 25 November 1999.
2 IMO: *Amendments to the Principles of Safe Manning*. A.955(23), 5 December 2003.

- Safe navigational, engineering and radio watches (according to regulation VIII/2 of IMO's STCW Convention);
- Safe mooring and unmooring of vessels;
- Management of the safety functions of the ship when employed in a stationary or near-stationary mode at sea;
- Performing operations, as appropriate, for the prevention of damage to the marine environment;
- Maintaining the safety arrangements and the cleanliness of all accessible spaces to minimize the risk of fire;
- The provision for medical care onboard ship;
- Ensuring safe carriage of cargo during transit;
- Adequate maintenance regarding the structural integrity of vessels;
- Ship operations according to the Ship Security Plan (SSP) etc., as specified by the International Shipboard and Port Facility Security (ISPS) Code[3];
- The ability to operate all watertight closing arrangements and maintain them in effective condition, and also deploy a competent damage control party;
- The ability to operate all on-board fire-fighting and emergency equipment and life-saving appliances, carry out such maintenance of this equipment as is required to be done at sea, and muster and disembark all persons on board; and
- The ability to operate the main propulsion and auxiliary machinery and maintain them in a safe condition to enable the ship to overcome the foreseeable perils of the voyage.

Undoubtedly, the rules and regulations used for the determination of manning have been created in the past where various factors, such as the characteristics of the area of operation, or the technological development in the maritime sector were integrated at much slower rates. Thus, although technology regarding vessel operations has advanced, rules and regulations have not followed closely these improvements. The result has been that in recent years, when vessels are faster and are equipped with more technologically advanced solutions and special characteristics (i.e. rapid turnaround times), flag state regulations do not allow the implementation in a straightforward and direct way of a crew reduction resulting potentially from these features. Typically there are specific agreements that take place between and the ship owner and the flag; the ship owner must prove (through *safety cases*) that his vessel can be safely operated with a crew smaller than the one the flag normally defines (Yamanaka[4]).

The scope of this paper focuses on the ability of the vessel to operate safely, in terms of watchkeeping, mooring/unmooring, and partially loading/unloading (the latter mainly in terms of monitoring) in conjunction with possible crew reduction due to onboard technological innovations.

3 SOLAS, Chapter XI-2, 12 December 2002.

4 Yamanaka, K., Gaffney, M.: *Effecting Manning in the Orient*. Washington, DC: US Department of Transportation, 1988.

In this context, the specification of crew composition is a complex task with a multidisciplinary nature; nevertheless, an analytical corresponding approach should commence from important aspects of the problem and the aforementioned safety issues (in relation to the level of ship automation) were regarded as such by the authors of the paper. The problem of estimating the optimal crew composition from both qualitative and quantitative point of view is a decision often based on legislative judgment and past performance/experience. A functional analysis of tasks carried onboard, as presented below, clearly shows that minor differences in vessel automation levels could lead to crew magnitude and composition dissimilarities.

The development of this effort was outlined by the momentum of the ship-owning part to incorporate the recorded operational and functional needs of a vessel into the existing manning framework. This means that safety issues that are related to the "software" of the maritime industry, namely crew, procedures, communications, as well as onboard practices, should be enriched and supported with proper task definitions and descriptions so as to enhance efficiency and sustainability of vessels. Thus, a functional/task analysis should always be conducted in such a way that it delineates the job specifications for all necessary onboard tasks, and consequently justifies all corresponding decisions and guidelines. The crew-determining methodology proposed in this paper addresses the identified safety issues, in a manner that covers the pinpointed gaps and provides a rational way that satisfies the well-known request of ship owners for a balanced and flexible determination of minimum manning levels. Moreover, the formulation of this method was motivated by the recorded delay of the responsible authorities to present a common structured approach concerning the influence of shipboard technologies on the modification of crew duties and responsibilities and, thus, on crew size and composition. In this line, according to IMO, the level of automation and integration of each candidate ship should be seriously considered when defining its crew, since these characteristics can affect the shipboard functions, and consequently the "quality" and difficulty of the duties performed by the respective crew members (IMO[5]).

The rest of this paper is structured as follows. Section 2 presents the functional analysis approach based on a revealed preferences questionnaire. The questionnaire was addressed to a large number of ship-owners and collected results concerning crew size alternation as a function of onboard automations. Section 3 briefly presents the implementation of the classification methodology that is utilized for the shipboard manning configuration. Section 4 gives the results compared to current practices and Section 5 concludes and proposes numerous issues for further discussion.

2 Data Collection, Vessel Automation, and Class Notations – A Preliminary (Crew) Task Analysis

Classification societies are responsible for the initial and periodical surveys and approval of ship hull and machinery. They classify all vessels according to their con-

5 *Op. Cit.* 1.

struction and *modus operandi* in predetermined registration types and consequently they enforce proper regulations for achieving their adequate safety and survivability. This way, each vessel receives a specific class notation that prescribes its technical characteristics and reveals its integration level. As shown in Figure 1, classification societies are involved into numerous stages of vessel production and subsequent lifecycle; the continuous feedback between the various stages of the chain ameliorates the efficiency of classification societies and enhances vessel performance and safety records.

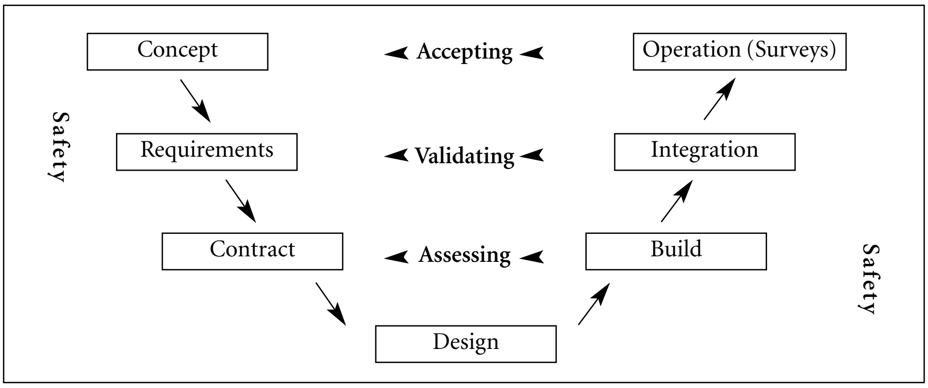

Figure 1: The role of classification societies in modern maritime industry.

The main class notations, regarding machinery operations and navigational competence of a ship, are presented in brief below (Lloyds Register[6]):

PUMS Denotes that all predetermined arrangements are such that the ship can be operated with its machinery spaces periodically unattended; periodically means that regular inspections and routine tests (every 4–6 hrs) should be conducted in order to assure continuous and reliable operation. (*Periodically Unattended Machinery Space*)

UMS Denotes that all predetermined arrangements are such that the ship can be operated with its machinery spaces unattended. (*Unattended Machinery Space*)

CCS Denotes that all predetermined arrangements are such that the ships machinery may be operated with continuous supervision from a centralized control station. (*Centralized Control Station*)

ICC Denotes that all predetermined arrangements are such that the control and supervision of ship operational functions are adequately computer-based.

6 Lloyds Register: *Lloyds Register's Rules and Regulations for the Classification of Ships.* London: Lloyds Registers Published Rules and Regulations, 2000.

It should be noted that the assignment of the notation ICC requires that the ship is also assigned at least one of the following notations: UMS, CCS, NAV and NAV1. (*Integrated Computer Control*)

IP Denotes that all predetermined arrangements of the machinery are such that the existing propulsion equipment and all the essential auxiliary machinery is integrated with the power unit for operation under all normal sea-going and manoeuvring conditions. It must also be noted that the specific system is to be bridge controlled; the propulsion equipment is supposed to incorporate an emergency means of propulsion in the event of failure in the prime mover. (*Integrated Power*)

NAV Denotes that a superior bridge layout and level of navigation equipment are provided.

NAV1 It denotes that the bridge layout and level of equipment are such that the ship is considered suitable for safe periodic operation under the supervision of a single watch-keeper on the bridge. (*Periodically One-Man-Bridge; at present, the perspective of having one person on duty at the bridge is at least under extensive consideration/review from IMO*)

IBS Denotes that an integrated bridge system is fitted to provide electronic chart display, track planning and automatic track following, centralized navigation information display, and bridge alarm management. Hence, it represents a combination of systems which are interconnected in order to permit central access to sensor information or command/control (MSC.64(67)). Moreover, the IBS standard has practically overlapped the *Integrated Navigation System* (INS, IEC 61209/Ed 1) in which the data from two or more exclusively navigation aids is combined in a uniform mode to provide an output that is superior to any one of the utilized aids. It is also mentioned that the assignment of the notation of IBS requires that the ship is also assigned either NAV or NAV1. (*Integrated Bridge System*)

The implemented analysis focused on the manning needs (referring to predetermined safety issues) of the selected class notations for representative types and sizes of vessels (i.e. handymax tanker, capsize bulk carrier etc). The key point was to determine (through a quasi-expert judgment approach) the necessary crew size and composition for a ship to operate with satisfactory efficiency and safety in the selected class notations.

Raw data were recorded with the help of a questionnaire and a number of personal interviews to shore and sea personnel of numerous shipping companies. The interviewees were asked to provide information about the crew capacity of a number of vessels at their current condition (automation level) and subsequently their estimation on the possible manning size and composition for specific chosen upgraded vessel class notations. In most cases, the *terminus a quo* referred to conventional vessels, which are the ones with neither remote control nor integration abilities onboard; hence, the adopted class notations were the following:

L0: Conventional vessel (as per above)
L1: UMS
L2: CCS
L3: IBS

The collected data address the ship-owning point-of-view which is based mainly on the operational capability of a ship to perform its tasks, e.g. sailing, mooring/unmooring, ballasting etc. It must be reminded though, that in real life manning issues are exclusively handled by flag authorities under strict regulations for the protection of the human life, cargo, hull, and the marine environment. Hence, the developed model should be justified as a proposition for crew assignment onboard a vessel integrating operational and safety needs, as defined earlier for the scope of this paper. In any case, it is the flag authority that should decide whether the resulting crew size and composition meets, in a realistic manner, the aforementioned issues; these are a fraction of the overall demands of IMO for adequate manning, nevertheless they constitute a satisfactory starting point (as a minimum threshold), since they address important safety aspects of the vessel. The specific model was assessed by the Danish and Swedish maritime authorities (in the context of the ATOMOS IV project) with encouraging results that reveal its potential to become an encouraging starting point for the efficient allocation of crew in vessels.

Thus, a functional task analysis is considered essential so as to trace and justify, in a realistic manner, the modified crew duties (mainly referring to safety), the altered crew composition and its potentially reduced size resulted from the diversification of class notation. The task analysis is the proper means to formulate the framework and define the structure of the requisite activities, procedures and personnel onboard vessels. An ample review was conducted regarding earlier research on shipboard functional analysis; it identified previous efforts that determined optimal manning records onboard various types of ships, according to their technological level (Liverpool Polytechnic[7], Denny[8], Ventikos[9], Quinlan[10]). However, all these approaches utilized similar methods, such as interviews, bottom-up analysis etc. Instead, functional

7 Liverpool Polytechnic and Collaborating Colleges: *Technology and Manning for Safe Ship Operations*. London: Department of Transport, Vol. 1 & 2, 1986.

8 Denny, M.: *Shipboard Productivity Method*. Washington, DC: US Department of Transportation, Vol. 1, 2 & 3, 1987.

9 Ventikos, N.P., Zacharioudakis, P., Dilzas, K., Lyridis, D. V., and Psaraftis, H. N.: *Retrofit Strategy Tool, Crew, Equipment & Cabling, and Other Cost Components, Parts I & II (ATOMOS IV Report)*. Athens: National Technical University of Athens, School of Naval Architecture and Marine Engineering, Maritime Transport, September, 2002.

10 Quinlan, J.R.: *Boosting, Bugging and C4.5*. In: *Proceedings of the 13th National Conference on AI*. Portland, Oregon: AAAI Press, pp. 725–730, 1996.

analysis allows an analyst to gain a broad overview of the main functions, which need to be performed to accomplish a particular task, such as mooring, anchoring etc. In general, high-level task analysis is undertaken in the following way (IMO[11]):

- Describe all system operations in terms of the tasks required for a certain operational goal;
- Consider all main goals associated with normal operations, maintenance, emergency situations, and recovery measures.

The recorded trend toward reduced operational costs (including crew costs) and increased maritime safety focuses on applying systems engineering. Figure 2 shows a similar approach for shipboard manning, where requirement analysis, task analysis, man machine trade-off survey, and organizational analysis are included. More specifically, task analysis addresses existing activities that support the current system and activities after the retrofit as required by the new automation/integration vessel procedures; the man-machine trade-off study produces a matrix that describes the shift of functions from the human element to the shipboard equipment (element of matrix manning).

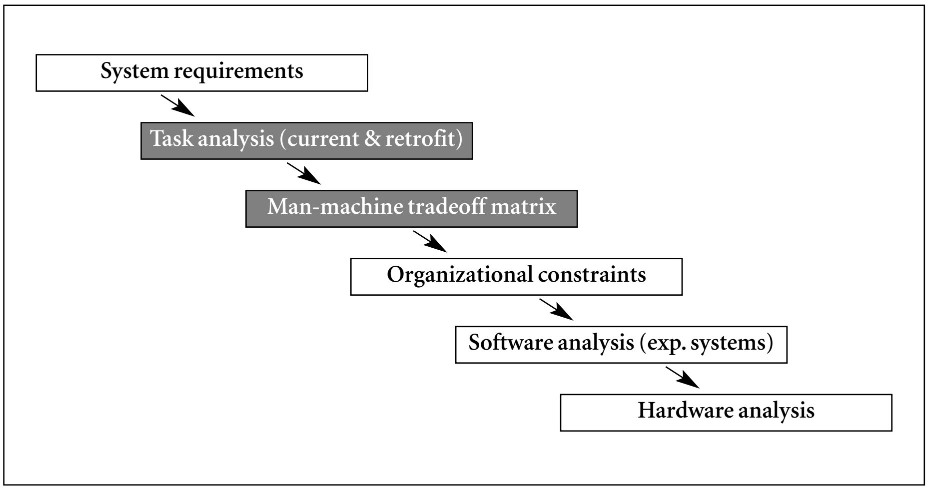

Figure 2: Systems engineering framework of shipboard manning.

The implemented task analysis approach covered certain safety topics related to human factor and to the man-machine tradeoff (mainly referring to bridge and engine watchkeeping and to mooring/unmooring procedures), in order to find possible crew alternations between different class notations of the examined vessels. In this way an extended list of on-board operations was surveyed pinpointing the ones that seem to be more influenced by the increasingly complex shipboard environment. The human

11 IMO: *Guidelines for Formal Safety Assessment (FSA) for Use in the IMO Rule-Making Process,* MSC/Circ.1023, MEPC/Circ. 392, 5 April 2002.

factor holds a leading role in this effort with the following safety concerns arising from crew allocation on a ship (National Research Council[12], Schuffel[13]):

- Fatigue issues (the regulations of STCW 95 were taken into account appropriately, i.e. a minimum of 70 hours of rest per crew member per week, excessive workloads etc);
- Watchkeeping standards and practices;
- Reduced training opportunities (the elimination of certain crew positions, such as the entry-level wiper, can reduce the opportunity for on-the-job training efforts);
- Physical demands on crew members (reduced crew sizes means fewer people available and capable to deal with emergency procedures); and
- Certification issues (the varying levels of shipboard technology complicates the qualifications needed for operating an integrated bridge system).

It must be noted that the developed model does not incorporate, the module of scheduled or extra maintenance that traditionally is carried out by the crew, mainly through overtime practices, or the module of preparedness in case of emergency situations. It is reminded that the specific methodology addresses safety issues, such as watchkeeping and mooring/unmooring (and monitoring loading/unloading) and it should be viewed as the starting point of an analytical approach (including cost benefit and operational aspects). Ship efficiency and safety will be impaired if reduced manning is responsible for the delay of required maintenance. For this reason, it is necessary to assure that definitive changes concerning the size and composition of crew resulting from ship technological and procedural step-up shall not affect any maintenance needs/activities that might be undertaken during voyage. Likewise, the methodology has not examined the factor of service continuity by crew members. This may be a considerable safety factor especially with sophisticated shipboard systems requiring advanced knowledge and it is related mainly to key personnel (Master, Chief Engineer, Chief Mate, and 1st Engineer). Repeated service on the same ship guarantees familiarity with the equipment, and many times encourages teamwork.

Task analysis assayed to integrate major components in various operational phases, in order to define the shipboard activities that should be carried out by the crew members for each of the selected class notations. More specifically, the vessels profile and numerous operating conditions were initially specified, in the context of estimating the respective manning requirements. Then, for each selected function (referring to safety: watchkeeping, mooring/unmooring, and monitoring loading/unloading procedures) the average corresponding time was calculated in accordance to the conclusion of the examined activity. Combining this information with the statutory

12 National Research Council: *Crew Size and Maritime Safety*. Washington, DC: National Academy Press, 1990.

13 Schuffel, H., Boer, J.P.A., van Breda, L.: *The Ship's Wheelhouse on the Nineties: The Navigation Performance and Mental Workload of the Officer on the Watch*. In: *Journal of Navigation*. Vol. 42(I), pp. 60–72, 1989.

permitted workload per day, per crew member and with the STCW watchkeeping standards, the number of persons required to conclude the specific shipboard function was calculated on a daily basis. Table 1 provides an indicative overview of all identified tasks that were candidates for possible crew reductions; the actual evaluation was based on watchkeeping duties and mooring/unmooring demands.

Furthermore, a detailed duty trade-off matrix was implemented so as to appoint and visualize all respective changes that resulted from the introduction of onboard technologies and the consequent step-up of vessel notation. Thus, it has been possible to determine the responsible crew member or equipment for each identified function based on expert group judgment and preliminary man-hour analyses. Table 2 to Table 4 present indicative examples of the work done concerning the manning needs of three different types of ships, in three separate operational phases and class notations; namely cargo carriage (loading/unloading) for a conventional aframax-sized double hull tanker, mooring (mooring-steering procedures referring to watchkeeping and emergency stand by) for a conventional capesize bulk carrier, and navigation in restricted areas (power and propulsion issues referring to watchkeeping and emergency stand by) for a UMS C10-class containership. It is reminded that crew composition in the selected target class types, which for the specific cases are CCS tanker, IBS bulk carrier, and CCS containership respectively, were provided by personal interviews of highly trained and experienced shore and sea personnel.

The aforementioned examples (Table 2 to Table 4) manifest that the installation of on-board automations and integration schemes change the job description for numerous crew ranks leading to more sophisticated and technology-dependent practices. Hence the need of enhanced education and training (i.e dual certification) might provide an adequate solution, especially for high ranked officers. Moreover, the class notation step-up can introduce significant crew reductions, since the shipboard equipment is in position to provide a more relaxed, structured and integrated working environment. It is reminded though once more, that all issues regarding the manning of ships are dealt by the flag authorities and the respective regulations.

Figure 3 presents the results from the interviews/elaboration for possible crew cutback of 2nd Engine Officers and of Wipers/Oilers on a Norwegian containership, referring mainly to watchkeeping – and excluding emergency stand by (Table 4) for navigation in restricted areas.

In the outline of the implemented task analysis approach, a number of technology-driven operating topics related to crew size and composition was identified by the interviewed stakeholders:

- *Operating procedures:* which functions shall be performed by the crew, or by external personnel (i.e. maintenance)?
- *Crew flexibility:* to what extent can crew members perform both deck and engine duties?

- *Job description:* will there be new obligations and responsibilities?
- *Training:* do crew members receive an enhanced training program regarding the introduction of advanced shipboard technologies?
- *Personnel criteria and procedures:* does management follow STCW and its regulations for watchkeeping, personnel enrollment, certification, crew assessment, physical condition etc?

Table 1: Tasks potentially examined for assessing crew duties and responsibilities (the table was constructed taking also into account requirements by the ISM Code and the STCW Convention).

Type of activities	Task/functions
Navigation	Watch keeping Man-machine interface Manoeuvring – Collision avoidance Voyage/passage planning Visibility & weather issues
Main engine operations	Watch keeping
Auxiliary deck operations	Mooring/unmooring Anchoring Cranes
Auxiliary equipment operations	Watch keeping Fuel transfer
Cargo handling	Loading/unloading Inspection Hold & tank cleaning
Ballast	Loading/unloading
Security operations	As outlined by the ISPS Code
General operations	Drills On-board training Bunkering Shipboard routines (ISM) Inspections Light deck maintenance Cleaning Cooking & catering
Emergency handling	Fire Pollution (SOPEP) Water intake

Table 2: Exemplary descriptive matrix for manning alternatives concerning indicative crew ranks on a Greek flagged tanker.

Tanker (Aframax), Greek flag				
Cargo carriage Loading/unloading				
	3rd Deck officers	Task demands	3rd Engine officers	Task demands
Conventional (current status)	2	physical attendance bridge/deck; rotation shifts (watchkeeping); other duties; emergency stand-by; communications	3	physical attendance pump room; rotation shifts (watchkeeping); other duties; emergency stand-by; communications
CCS (interview/ analysis)	0	duties covered by equipment and higher ranked officers	1	physical attendance central control room; sampling attendance pump room; rotation shifts (watchkeeping); other duties

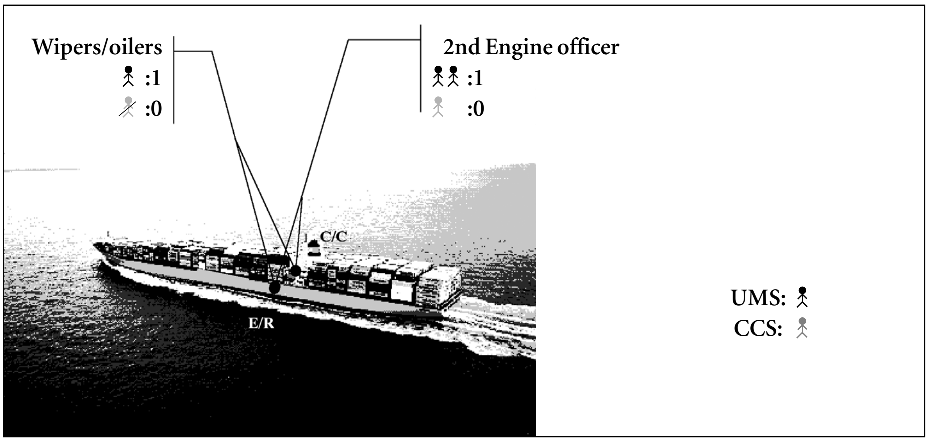

Figure 3: Visualized manning alternatives on a Norwegian flag containership based on the level of technology onboard.

Table 3: Exemplary descriptive matrix for manning alternations concerning indicative crew ranks on a Maltese flagged (dry) bulk carrier.

Bulk carrier (capesize), Maltese flag				
Mooring mooring-steering				
	2nd Deck officers	Task demands	3rd Deck officers	Task demands
Conventional (current status)	2	physical attendance bridge/deck; rotation shifts (watchkeeping); other duties; emergency stand-by; communications	3	physical attendance bridge/deck; rotation shifts (watchkeeping); other duties; emergency stand-by; communications
IBS (Interview/analysis)	0	duties covered by equipment and higher ranked officers	1	duties covered by equipment and higher ranked officers
Tradeoff description	high integration and automation level, integrated/accumulated readings and control at one or more bridge stations, advanced shipboard technology and networking, differentiation in duty demands and "quality"			

In this way, a realistic task analysis is formulated. This analysis points towards possible new duties and changed (reduced) crew sizes, as a result of the additional innovative shipboard technology and automation. The main goal of this effort has been to produce the necessary background for the manning-defining model; nonetheless, the functional analysis itself carries a significant value, since it represents one of the most basic steps in the overall process.

The end result has been the development of a database, which was analysed under the umbrella of the classification tree methodology. This database contains in total 480 records, and includes data regarding 120 vessels for all 4 chosen automation/integration levels. The database accounts for the following ship types:

- Tankers;
- Bulk Carriers;
- General Cargo Vessels;
- Containerships;

- Reefers; and
- Ro-Ro's.

Table 4: Exemplary descriptive matrix for manning alternations concerning indicative crew ranks on a Norwegian flagged containership.

Containership (C10), Norwegian flag					
Navigation in restricted areas **Power and propulsion**					
	2^{nd} Engine officers	Task demands	Wiper/ oilers	Task demands
UMS (Current status)	2	(periodic) physical attendance E/R; rotation shifts (watchkeeping); other duties; emergency stand-by	1	(auxiliary) physical attendance E/R; other duties; emergency stand-by
CCS (Interview/ analysis)	1	physical attendance central control room; sampling attendance E/R; rotation shifts in conjunction with higher ranked officers (watchkeeping); other duties	0	duties covered by higher ranked officers and equipment
Tradeoff description	remote monitor and control capabilities, centralized control structure (including E/R), department separation, differentiation in duty demands and "quality"			

The implemented crew ranks are presented below with the additional remark that crew was divided in three main categories: deck crew, engine crew and support crew. This was necessary because of the quality and type of data that were provided by all contacted shipping companies. Therefore, each resultant crew composition plan incorporated the following ranks:

DECK CREW

- Captain (CPT);
- Chief Mate (CM);
- 2^{nd} Officer (SECOF);
- 3^{rd} Officer (or Apprentice Deck Officer – THROF);
- Boatswain (BOS);
- Able Body (AB);

ENGINE CREW

- Chief Engineer (CEN);
- 2^{nd} Engineer (SECEN);
- 3^{rd} Engineer (THREN);
- Electrician (or Apprentice Engine Officer – ELE);
- Oiler/Wiper (WO);

SUPPORT CREW

- Cook (COOK);
- Steward (STEW).

Relevant data was collected by questionnaires and extensive personal interviews regarding companies based in Greece. The interviewed personnel were both marine officers and shore engineers, in order to acquire an overall view of the possible results from the retrofit (referring to manning practices in vessels). Hence all ships involved were Greek owned, but were registered under various flags: the majority of them carry the Greek flag, some of them are under the flags of Panama, Liberia, Cyprus and Malta and one sails under the Norwegian flag. *However, there was no attempt to link/adapt the answers from the interviews to the corresponding legislation (manning certification) of any of the above flags;* the analysis was exclusively based on safety/STCW considerations, such as watchkeeping, mooring/unmooring (and monitoring loading/unloading). Moreover, the methodology was enhanced by a *structured validation scheme* in order to assure adequate accuracy and ability to generalise; it was decided to implement the proposed model to a number of vessels of various types and flags (mainly EU flags) of known crew composition. The validation scheme is further described in Section 4.

3 Implementation of the Classification Methodology

The implemented methodology functions under the generic approach of classification resulting either to respective tree structures, or to rule-based forms; this type of analysis relates each dependent variable/class (*manpower per rank*) to the selected independent variables (*automation level, ship type, size (GRT) and main engine (BHP)*).

Classification tree analysis is one of the main techniques used for *data mining*. It attempts to reveal patterns, to generalize, and to estimate an accurate output for several ranges of input data. Classification trees can be sometimes quite complex. To overcome this difficulty the paper implements an additional form for the representation of the classification model: the rule-based structure (*IF…THEN rules*). If the tree structure is too complex to handle, it is transformed into a rule-based approach. Hence, class approximation using the classification tree technique, develops a qualitative and quantitative language to describe the knowledge achieved from the training data set. In general, the algorithm leads to a tree construction effort, which evolves through nodes and leaves. Each node represents a control procedure that accepts or rejects the way through (according to the aforementioned independent variables). Every final leaf corresponds to a specific class of the dependent variable (that is manpower per rank, such as 3 Able Bodies or 2 Second Officers).

In general, this type of methodology utilizes as input:

a) groups of recorded attributes that are related to separate sets (e.g. to each crew rank), and
b) a cluster of classes that correspond to the aforementioned sets (e.g. such as the number of members per crew rank that satisfy all corresponding safety demands during a voyage).

Hence, the goal of such an effort is the formulation of various branches (including rule-based options) that provide descriptive information about the resulted division and allocation of classes regarding the examined set (e.g., the BHP or the GRT limits for reducing the number of Second Engine Officers, as result of the automation enhancement of ships).

4 Results and Validation (Comparison with Current Practices)

This section presents the results emerging from the implemented methodology on determining crew composition for each level of installed automation technologies. Moreover, the approach and its results are validated through the assessment of current practices and the consequent comparison between the various stages. This is done with a *structured validation scheme* in order to ensure the accuracy and generalization of the effort. In this context it was decided to implement the model to a number of vessels of various types and flags (mainly EU flags) of known crew composition and class notation (automation level) and to receive the corresponding results for all these ships in tree or rule-based structure for all four of the predefined automation/integration levels. The results are given in two different graphical forms. The first is through a classification tree and the second deals with a concatenation of rules. It must be pointed out that both of these versions reveal the same amount and "quality" of information and the occasional preference of one over the other is clearly case driven (in order to achieve better visualization of the results). An illustrative classification tree as well as a set of rules is given in the Appendix. In the outline of the validation scheme, the selected EU-flag vessels are given in Table 5.

The model was applied to all vessels of Table 5 and for the selected automation/integration levels already described; in this respect, vessels No 1, No 9, No 10, and No 14 that do not belong to the conventional notation but to the UMS category were modeled for levels 2 and 3 and the evaluation of the model performance was conducted accordingly at L1. A similar procedure was followed for vessels No 7 and No 11, which were classified as CCS vessels; for these ships, the implementation was done for L3 and the evaluation of the methodology was based on the comparison of the results at L2 with the real crew records of the CCS vessels.

Table 5. Vessels under consideration for the validation scheme.

No	**Ship type**	**GRT**	**Flag**	**Level of automation**
Vessel 1	Tanker (LPG)	2000	U.K.	UMS (L1)
Vessel 2	General cargo	12376	Cyprus	Conventional (L0)
Vessel 3	Tanker	17882	Portugal	Conventional (L0)
Vessel 4	Tanker	4450	Italy	Conventional (L0)
Vessel 5	RoRo	14406	Sweden	Conventional (L0)
Vessel 6	Bulk carrier	23602	Spain	Conventional (L0)
Vessel 7	General cargo	2999	Netherlands	CCS (L2)
Vessel 8	General cargo	12778	U.K.	Conventional (L0)
Vessel 9	Containership	81488	Denmark	UMS (L1)
Vessel 10	Containership	70000	Greek	UMS (L1)
Vessel 11	RoRo	7095	Cyprus	CCS (L2)
Vessel 12	Tanker	18999	France	Conventional (L0)
Vessel 13	Bulk carrier	35191	Italy	Conventional (L0)
Vessel 14	Tanker	19899	Spain	UMS (L1)

Table 6 gives the prediction accuracy of the introduced manning model at the stated (standing) notation level of each of the validation vessels (Table 5). For example, a tanker under the British flag, at level 1 (UMS) operates with an actual crew size of 12 seafarers (including higher and lower ranks of crew) while the corresponding model prediction equals to 11 crew members; this is translated to a difference of 8.333%. It can be derived from Table 6 that the majority of the model's predictions are satisfactory within approximately 1 seafarer per 10 crew members (difference ranging from –8.333% to 15%). The recorded model results seem to be on the safe side (in comparison to the provided figures) ensuring this way the fulfilment of numerous shipboard duties and obligations past the implemented watchkeeping, mooring/unmooring initial conditions. According to Table 6, there is a 7.1% chance that the model might predict a crew that falls short by one or more crew members in comparison to the actual crew size at the selected automation class (a normal fitted distribution with a p-value of 0.7515 gives no basis to reject the hypothesis that *the fitted distribution actually corresponds to the data set from the validation scheme*).

Table 6. Cross validation test results.

Type	Flag	Level	Administration	Model	Difference	%DIFF
Tanker	UK	UMS	12	11	–1	–8.333
GC	Cyprus	CONV	22	22	0	0.000
Tanker	Portugal	CONV	26	27	1	3.846
Tanker	Italy	CONV	20	23	3	15.000
RoRo	Sweden	CONV	20	21	1	5.000
BC	Spain	CONV	24	25	1	4.167
GC	Netherlands	CCS	7	8	1	14.28
GC	UK	CONV	23	22	–1	–4.348
Cont	Denmark	UMS	17	19	2	11.765
Cont	Greek	UMS	17	19	2	11.765
RoRo	Cyprus	CCS	12	11	–1	–8.333
Tanker	France	CONV	21	24	3	14.286
BC	Italy	CONV	22	25	3	13.636
Tanker	Spain	UMS	17	19	2	11.765

Table 7 gives an analytical example for a UMS container vessel under Greek flag (GRT 70000, BHP 62200, vessel No 10) and displays in detail the aforementioned results and trends per crew rank. Hence it is shown that from 17 crew members under the UMS notation the containership will only need a crew 11 (according to the selected criteria) if upgraded to IBS; that equals to a reduction of about 35% for the specific vessel.

Even though the above validation results are based upon a small sample of EU–flag vessels, the presented exercise supports the general conjecture that the proposed crew composition approach is in a position to produce reasonable and realistic results with reference to safety requirements

5 Conclusions

As mentioned earlier, the specific intended use of the tool developed in this paper was to help a ship owner decide whether it is cost-beneficial to retrofit a conventional vessel with advanced technologies that would entail a reduced crew. To do so, an estimate of the reduced crew was necessary, and this paper suggested a systematic way of doing so, by establishing a decisional framework for the calculation (and justification) of crew size and composition based on safety/operational and financial requirements (a long-standing demand of vessel owners and operators). More specifically,

Table 7. Cross validation case-driven results (Greek containership)

	UMS (administration)	UMS (model)	CCS (administration)	CCS (model)	IBS (administration)	IBS (model)
Total	17	19	–	15	–	11
Captain	1	1	–	1	–	1
Chief officer (mate)	1	1	–	1	–1	0
2nd Officer	2	2	–	1	–	0
3rd or Apprentice Deck officer	0	0	–	0	–	0
Chief engineer	1	1	–	1	–	1
2nd engineer	2	1	–	1	–	1
3rd engineer	1	2	–	1	–	0
Electrician or Apprentice Engine Officer	1	1	–	0	–	0
Boatswain	1	1	–	1	–	1
Deck or Able body	4	5	–	5	–	4
Wiper /oiler	1	1	–	0	–	0
Cook	1	1	–	1	–	1
Steward	1	2	–	2	–	1

the innovative methodology presented here incorporates issues of watchkeeping, mooring/unmooring, and loading/unloading (limited to monitoring of procedures) and gives realistic manning figures according to the level of vessel automation (that is class notation).

Hence, the proposed method integrates information about crew size as a function of 4 predefined levels of degrees of automation (established through expert judgment) and consequently analyzes/elaborates it using data mining techniques. The model can be applied to any ship design and it can predict its crew size and composition in a manner that all set requirements are adequately and sufficiently met. This way, all involved stakeholders, including ship owners deciding on automation retrofit, are able to know the approximate tolerable size and crew composition resulting from the retrofit investment.

Furthermore, it is shown that the exploitation of technological upgrades can result in financial benefits in terms of reduced manning. The implemented model shows a significant stability in terms of prediction accuracy: suggested crew magnitude as a function of automation levels that does not deviate more than 15% from the actual records in the validation set of vessels (about 1 seafarer per 10 crew members). In this context, the model results for higher class notations are considered realistic (as far as the selected safety/operational activities and manpower needs are concerned) and therefore, they are in position to give a broad outline of the expected crew reduction as result of the shipboard automation retrofit/enhancement (Table 7 reveals a 35% crew reduction when upgrading from class UMS to IBS for the specific vessel with the Greek flag.)

In terms of possible extensions of this work, the proposed methodology could be viewed as a solid starting point for consequent development of an overall analytical crew estimating approach, according to the entire set of IMO manning principles. In that sense, the tool developed herein, or possible modifications thereof, could assist maritime policy makers in the analysis of manning alternatives for advanced technology vessels. The recorded results provide for watchkeeping and mooring/ unmooring and, partially, loading/unloading (the latter mainly in terms of monitoring) tasks with reference to ship automation level. This way they formulate a realistic basis for a consequent effort aiming to cover all manning properties, i.e. maintenance needs, ship security requirements according to various factors, such as the construction and equipment of the ship, the cargo to be carried, the frequency of port calls etc (IMO[1,2]). Such studies may prove themselves very useful to maritime stakeholders and policy makers, namely flag authorities and ship owners, and may contribute to the decisional/proactive framework for the protection of human life, hull, cargo, property of third parties and of the marine environment.

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Appendix

Examples of classification trees and concatenation of rules

The following illustrative example refers to a classification decision tree for the attribute/rank of *Electricians* (Ventikos[9]). The error in the specific structure is 7.7%, which is translated into an efficiency index of more than 90%.

- AUTOMATION LEVEL = [L0: CONV]:
  - GRT <= 2000: 0
  - GRT > 86000: 1
  - GRT <= 86000:
    - BHP <= 20800: 1
    - BHP > 20800: 2
- AUTOMATION LEVEL in [L1: UMS–L3: IBS]:
  - AUTOMATION LEVEL = [L3: IBS]: 0
  - AUTOMATION LEVEL in [L1: UMS–L2: CCS]:
    - GRT > 129202: 1
    - GRT <= 129202:
      - TYPE = RORO: 0
      - TYPE = REEF: 0
      - TYPE = CONT: 0
      - TYPE = BULK:
        - GRT <= 44289: 1
        - GRT > 44289: 0
      - TYPE = GC:
        - GRT <= 14512: 0
        - GRT > 14512: 1
      - TYPE = TANKER:
        - AUTOMATION LEVEL = [L2: CCS]: 0
        - AUTOMATION LEVEL = [L1: UMS]:
          - GRT <= 49998: 0
          - GRT > 49998:
            - GRT <= 86000: 1
            - GRT > 86000: 0

(Size: 18; Errors: 7.7%)

The next illustrative example belongs to the category of rule-based classifiers and it covers the attribute/rank of *Second Deck Officers* (Ventikos[9]). The efficiency of the model in the specific case is more than 95% while the number of rules that describe the problem is 12 only.

Rule 1:
AUTOMATION LEVEL is L3: IBS
GRT <= 4450
–> class 0 [zero *Second Deck Officers*]
Rule 2:
TYPE = REEF
AUTOMATION LEVEL is L2: CCS
GRT <= 3852
–> class 0
Rule 3:
TYPE = TANKER
AUTOMATION LEVEL is L2: CCS
GRT <= 3852
–> class 0
Rule 4:
AUTOMATION LEVEL in [L0: CONV – L1: UMS]
GRT <= 3852
–> class 1 [one *Second Deck Officer*]
Rule 5:
TYPE = GC
AUTOMATION LEVEL in [L0: CONV – L2: CCS]
GRT <= 3852
–> class 1
Rule 6:
AUTOMATION LEVEL is L2: CCS
GRT > 56311
GRT <= 152374
–> class 1
Rule 7:
AUTOMATION LEVEL is L3: IBS
GRT > 4450
–> class 1
Rule 8:
TYPE = CONT
AUTOMATION LEVEL is L2: CCS
–> class 1
Rule 9:
TYPE = RORO
AUTOMATION LEVEL is L2: CCS
–> class 1

Rule 10:
TYPE = REEF
AUTOMATION LEVEL is L2: CCS
GRT > 3852
–> class 1
Rule 11:
AUTOMATION LEVEL in L0: CONV – L2: CCS
GRT <= 152374
–> class 2 [two *Second Deck Officers*]
Rule 12:
AUTOMATION LEVEL in L0: CONV – L2: CCS
GRT > 152374
–> class 3 [three *Second Deck Officers*]
(Rules 12, Errors: 3.3%)