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The application of AHP in the development of a taxonomy of merchant marine deck officers' non-technical skills (NTS)

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Abstract—The importance of NTS has been realised in many safety critical industries. Recently the maritime domain has also embraced the idea and implemented an NTS training course for both merchant marine deck and engineering officers. NTS encompass both interpersonal and cognitive skills such as situational awareness, teamwork, decision making, leadership, managerial skills, communication and language skills. Well-developed NTS training allow ship's officers to recognise quickly when a problem is developing and manage the situation safely and efficiently with the available team members. As a result, the evaluation and grading of deck officers' NTS is necessary to assure safety at sea, reduce the effects of human error on-board ships, and allow ship board operations to be performed safely. This paper identifies the skills necessary for deck officers to effectively perform their duties on the bridge of a ship. To achieve this, initially, a taxonomy of deck officers' NTS is developed through a review of relevant literature and the conducting of semi-structured interviews with experienced seafarers. Subsequently, NTS weighting data is collected from experienced seafarers to allow the weight of each element of the taxonomy to be established by the use of the Analytical Hierarchy Process (AHP).

Keywords—Non-technical skills, human element, leadership, analytical hierarchy process.

I. INTRODUCTION

The aim of this paper is to produce a taxonomy of NTS for deck officers. This is to be done by reviewing relevant literature and then going on to collect information from experienced seafarers. With the taxonomy established the next stage is to determine the weight of each of its elements by the use of the Analytical Hierarchy Process (AHP).

Within this research the term 'NTS' is used to describe the portion of deck officers' attitude and behaviour that is not directly related to the technical skills required to navigate a ship or to use bridge equipment. This includes social and cognitive skills relating to teamwork, leadership, decision making, situation awareness and workload management. Research conducted into anaesthetists' NTS [1] importance is given to good NTS. By enabling anaesthetists to work in such a way as to reduce the chances of problems occurring, they allow the anaesthetist to be fully aware of the situation thus he or she will be able to anticipate the problem or deal with unexpected occurrences. The same could be applied to the shipping industry as good NTS allow the deck officer to recognise the problem quickly and manage the situation and team safely and effectively [2].

Whilst there are existing skill taxonomies and behavioural marker systems being used in training and assessment in other safety critical industries around the world, in the maritime industry, skills taxonomy is a relatively new concept. It is important to develop a skills taxonomy which can be used for the assessment of deck officers in a simulated ship's bridge environment. Based on a literature review of NTS and their use in the other safety critical industries, this has provided a valuable input as it indicates the type of areas that need to be addressed. Firstly, it was considered to conduct interviews with experienced seafarers to identify the NTS for deck officers.

II. Literature Review

Human factors researchers use different methods of task analysis to design and evaluate systems, equipment and training. Cognitive Task Analysis (CTA) allows the task being carried out to be broken down into its constituent parts [3] . Task analysis is a key component of training needs analysis as it identifies the knowledge and skills needed to conduct a particular task. Crandall *et al.* [4] defines the purpose of CTA as to capture the way the mind works, to capture cognition. A researcher who is carrying out a CTA study involves trying to understand and describe how the participants view the work that they are doing and how they make sense of events. "If people are making mistakes in the workplace, the CTA study should explain what accounts for these mistakes" (ibid).

Since many of the skills required for deck officers are cognitive, it was considered necessary to conduct CTA. "CTA identifies and describes the cognitive structures (knowledge-base and representation skills) and processes (attention, problem solving, and decision making) underlying job expertise, and the knowledge, and skills required for similar job components" [5].

Crandall *et al.* [4] identified the following three primary aspects of CTA:

2.1 Knowledge elicitation (Methodology)
2.2 Data analysis (Methodology)
2.3 Knowledge representation (Results).

For a successful CTA study each of these aspects must be undertaken. Many researchers equate CTA with the first aspect, knowledge elicitation, because traditionally this has received most attention. However, Crandall *et al.* [4] argued that a good analysis of data is also necessary, otherwise the collection of data is meaningless.

Knowledge Elicitation

Knowledge elicitation is used to obtain information about what people know and how they know it: the judgement, strategies, knowledge, and skills that underlie performance. One way of classifying CTA knowledge elicitation is by the way that the data is collected. Four methods of collecting data are listed as follows (4. Crandall *et al.*, 2006):

Self-Reports

Self-reporting (people talking about or otherwise recording their behaviour and strategies) methods vary from structured formats, such as surveys and questionnaires, to open-ended formats like diaries and logs. The advantage of a self-reporting format is that data collection does not require a skilled interviewer to be present, making the system more efficient. The quality of data generated depends in part on the structure of the questionnaires used. The research questionnaire method is useful for quantitative data collection as it can reach a wide variety of respondents through electronic media. The disadvantage of this method is that structured questionnaires do not allow for an element of discovery and exploration [6].

A questionnaire method was considered inappropriate for the purpose of this paper as the data required is qualitative and would require using an exploratory technique to probe for clarification of the information provided.

Direct observation of performance or task behaviours

Direct observations can be conducted either in the workplace or in a simulated environment. If on-site observations are feasible researchers are strongly recommended to take advantage of the opportunity. It is simply not possible to get the information obtained by this method in any other way. "Observations provide opportunities for discovery and exploration of what the actual work demands are; what sorts of strategies skilled workers have developed for coping; how work flows across the environment, the team, and the shift and communication and coordination issues" [4].

For the purpose of this paper it is not practicable to monitor officers in 'real life' situations, because of the risk to human life and the environment. As a result of this the alternate route of studying deck officers' NTS in a simulated bridge environment was pursued.

Automated collection of behavioural data

Endsley [7] developed SAGAT (Situation Awareness Global Assessment Technique) to assess situation awareness. SAGAT is based on de Groot's strategy for comparing chess players at different skill levels. De Groot's method was to have a chess player study a game in progress and then unexpectedly remove all pieces. The players would then be asked to replace all the pieces. De Groot found that the more skilled players were more accurate in reconstructing the board than novice players.

Similarly, the SAGAT method is used in the aviation industry by 'time freezing' a simulation in the midst of a pilot's session. This is done by switching all the instruments off and then asking the pilot to reconstruct the instrument values. According to Endsley [7], the better a person's situation awareness, the more accurate the reconstruction.

Interviews

There are a number of different approaches to interviewing. However, the majority of these fall in to two categories: structured interviews or semi-structured interviews. The disadvantage with structured interviews is that the interviewer has a set list of questions to ask and therefore the interviewee's responses are restricted to these questions. In addition, the interviewer has no flexibility to investigate further if an interesting opportunity presents itself. In semi-structured interviews there is more flexibility for the interviewer to further investigate issues that arise and questions can be adapted to meet the circumstances. However, in this approach the interviewer needs to have a degree of understanding of the subject area to be able to identify opportunities to probe further and what to ask [8].

The semi-structured interview method allows the collection of as much information as possible on the critical decisions made on the bridge of a ship within an allocated time period. This method is deemed appropriate as whilst watchkeeping on the bridge of a ship many factors are cognitive, and therefore unseen, the only practical way to investigate these skills is through subjective assessment. However, a particular concern of using recalled events is that those concerned may not be able to accurately remember the events that took place or their memory may be subject to bias [8].

III. Methodology

To develop a taxonomy of deck officers NTS, semi-structured interviews were conducted with experienced deck officers at management level to help identify the key skills to be included. A semi-structured method of interviewing was considered suitable to extract maximum information from the interviewee regarding the NTS of the deck officer. The aim of the interview was to identify the non-technical aspects of deck officer's watchkeeping duties.

The interview was divided into three parts:

Part 1: Performance example – The interviewee was asked to describe a real case from his career that was particularly challenging which really tested his NTS. The example can be a real critical incident/near miss or a normal case where the experience and NTS were a significant outcome. The interviewee was asked in advance if he could think of this example before the interview. This case was then discussed to identify the most significant NTS components.

Part 2: Distinguishing skills – The interviewee was asked to consider the skills necessary for a deck officer to effectively perform their duties on the bridge of a ship.

Part 3: Weighting task – The interviewee was asked to assign a weight to each of the NTS taxonomy elements. The weights assigned by experts were the aggregated by the AHP method.

The first criterion for the selection of the participants was that they must hold a Master Mariner certificate of competency. The other criterion for taking part in the study was that the interviewees volunteered to take part. Fletcher *et al.* [8] argues that those people who are very interested in human factors will be more inclined to volunteer and this might lead to potential biases. However, given the sensitivity of the information being discussed, it would be unethical to interview unwilling participants. In the 'identification and measurement of anaesthetists' NTS twenty five to thirty interviews were considered acceptable initially and they received a very good response from consultant anaesthetists to volunteer (ibid). The researcher in this project visited the World Maritime University, Malmo, to conduct interviews with experienced master mariners pursuing further studies. The researcher's aim was to conduct ten to fifteen interviews for this research but could only manage twelve interviews in total.

Based on a review of relevant literature and input from interviewees, a skills taxonomy for deck officers was identified (Figure 1), which is been confirmed by expert interview participants.

GOAL	CRITERIA	SUB-CRITERIA
Deck officers' non-technical skills	Teamwork	Teambuilding and maintaining
		Considering others
		Supporting others
		Communication
		Information sharing
	Leadership and managerial skills	Use of authority and assertiveness
		Providing and maintaining standards
		Planning and co-ordination
		Workload management
		Prioritisation
		Task delegation
		Initial crisis management
	Situational awareness	Awareness of bridge systems
		Awareness of external environment
		Awareness of time
		Situation assessment
	Decision making	Problem definition and diagnosis
		Option generation
		Risk assessment and option selection
		Outcome review

Figure 1: Taxonomy of Deck Officers' Non-technical Skills

The criteria and sub-criteria elements of the skills taxonomy are explained as follows:

A. Teamwork (TW)

There has always been a need for people to work together as a team. When acting in coordination their efforts can achieve objectives that contribute towards the overall aims of an organisation. This has become increasingly important as organisations have increased in size and become more complex [9]. In an environment of rapidly changing organisational structures, teams are the best way to enact strategy. Organisations utilizing team-based structures can respond quickly and effectively in the modern fast-changing environment [10].

Team working is very important to most work settings but is especially important in higher risk industries such as aviation, nuclear power, firefighting, and maritime. Teams typically must function effectively from the moment they are established to achieve their goal. Team members must have a common understanding of how they will be expected to work together during the manoeuvring of a ship [11]. For instance, onboard a ship, effective operation is highly dependent on the level of team performance involving skills such as communication, co-ordination, co-operation and control [12].

Team-building and maintaining

Team-building is a process of facilitating a group to accomplish a common task, "a process by which members of a group diagnose how they work together and plan changes which will improve their effectiveness" [13]. Onboard ships when a new crew joins team-building events are rarely organised because of the busy schedule. Teams are built during the course of work.

Considering others

In the Crew Resource Management course of the aviation industry 'considering others' is defined as "acceptance of others and understanding their personal condition" [14]. Considering others and supporting others could be grouped together as one element. However the difference is a team member may request support whereas consideration may come from management without any such request being made.

The Chief Officer's consideration of a crew members mental state is very important on-board a ship. Especially for watchkeeping crew members. Considering providing the crew with proper rest periods and breaks during busy periods would improve their efficiency.

Supporting others

Team support refers to a broad spectrum of behaviour, such as: emotional team support, information team support, instrumental team support, and appraisal team support. Emotional team support refers to sympathetic understanding of another's emotional state. Information team support refers to team members' exchange of necessary information. Instrumental team support focuses on practical task support that team members offer each other. Appraisal support refers to helping each other in making sense of any problem situation [15].

As teams are the common work unit in today's organisations the value of supportive discretionary behaviour in those teams is proving crucial [16]. The more team members provide support to each other, the greater the improvement in team members' mental health and team performance [9].

Superior officers' support may be available in many forms onboard ships such as a new sailor being bullied by others such that he approaches the chief officer for support or the second officer needs the master's support in the appraisal stage of the passage planning.

Communication

One of the core skills central to effective and safe production and performance in any high-risk industry is communication. Yusof [17] believes that the purposes of communication in group work are regulating, controlling, motivating, expressing feeling and conveying information. Blundel [18] believes that most conflicts and crises that happen inside an organisation are particularly caused by lack of transparent communication among members of the organisation.

Information sharing

Information gathered by one team member can be transferred to his team members through feedback, help, advice or explanation. Exchange of information between team members brings information sources together and manipulates it into new information structures [19].

Distributing information from different sources among bridge team members (such as position, tidal stream, available depth or traffic) is called the Information Distribution Process [20]. Information sharing or knowledge sharing within teams may occur via the advice-seeking behaviour of team members. A master on the bridge needs information about traffic or drift the ship is experiencing, as a master is likely to become more competent in handling the task [21].

B. Leadership and managerial skills (LM)

The team leader is responsible for building an efficient team in order to boost task performance by ensuring safe and efficient team functioning. To do this it is important for a leader to demonstrate honest and ethical behaviour that serves as an example for the other team members. Maintaining team moral through confidence, a positive attitude and commitment to the task in hand will allow goals to be accomplished successfully [22].

A widely known example of poor leadership is the Titanic disaster. Captain Edward J. Smith was persuaded by White Star Line officials to proceed at a faster speed than had been planned for so that the ship would arrive in New York a day early. Captain Smith ordered the crew to light the last two boilers and bring the ship's speed up to twenty two knots. However, he did not add extra lookouts to the bridge team to watch for icebergs even though the ship's route took it through a known ice field. The ship hit an iceberg and one thousand five hundred people lost their lives. It was the poor leadership demonstrated by Captain Smith, relying too much on technology and misplaced confidence, that played a key role in contributing towards the disaster [12].

Use of authority and assertiveness

Flin *et al.* [14] describes 'Use of Authority and Assertiveness' as creating a proper challenge response atmosphere. The authority of a master on board a ship should be adequately balanced with assertiveness and other bridge team members' participation. If the situation requires, decisive actions are expected (ibid) such as in pilotage waters when the master of a ship doubts any of the pilot's actions.

Providing and maintaining standards

The master as a leader must comply with standard operating procedures for task completion. If the situation requires, it may be necessary to deviate from the standard procedures. Such deviation should take place with consultation with other bridge team members. Any deviation from standard procedures should be mutually supervised by the bridge team members [14]. The Captain of the Costa Concordia did not maintain the standard operating procedures on 13th Jan 2012 and decided to change his original voyage plan without the agreement of the company and local authority and passed the vessel too close to the Giglio Island, Italy. As a result the cruise ship grounded on the rocks of Le Scole with thirty two persons dead and sixty injured [24].

Planning and co-ordination

An appropriate system of organised task sharing and delegation needs to be established to avoid fluctuation of workload and to achieve high performance. A ship's master needs to make sure all bridge team members understand the goals, plans and intentions to communicate well. This will ensure a good co-ordination among the team members in all activities [14].

Comprehensive planning is required to make safe passage from the loading port to the discharging port. Over the years it has been observed that many ships involved in groundings, collisions and other contact incidents was due to poor passage planning or deviating from the planned passage [24]. The passenger vessel Balmoral, carrying two hundred and thirteen passengers and nineteen crew members, grounded on Dagger Reef, Gower Peninsular, on 18th October 2004, in fine weather and good visibility. The reason of grounding established that the master deviated from the planned track and took the vessel even closer to land [25].

Workload management

A major element of workload management is shifting the workload from busy times to quiet times. This will be done at the planning stage and identifies when high workload periods will occur. Mismanagement of workload will degrade bridge team performance. As a result, tasks need to be evenly distributed among the other bridge team members. A leader will need to identify and resolve the signs of stress and fatigue so that performance is not affected [14].

MV Cosco Hong Kong grounded over Lixin Pai reef, in the South China Sea, in 2009, as a result of the increased workload on the OOW. The vessel was on a passage from Xiamen to Nansha, China at a speed of twenty one knots when she encountered a large number of fishing vessels in the Dadanwei Shuidao channel. Even with the presence of a lookout/helmsman, the OOW manoeuvred the vessel himself by using the autopilot to the south of the track to keep clear of the fishing traffic. In doing so he forgot about the presence of the Lixin Pai reef, over which the charted depth was only 3.1 metres, which was highlighted as a danger on the paper chart in use [26]. Although he should have used a helmsman to steer the vessel and he himself should have concentrated on the other tasks, due to poor workload management he manoeuvred the vessel by using the autopilot.

Prioritisation

Clear prioritisation of primary and secondary operational tasks should be made by the leader. Primary tasks are those tasks that a sufficiently skilled crew is required for such as harbour approaches and secondary tasks are routine maintenances jobs. Secondary operational tasks are prioritised to retain sufficient resources for primary bridge duties[14], such as ship's crew should not be engaged in heavy duties before port approaches instead priority should be given to retain sufficient rested crew members available for approach duties.

Task delegation

When tasks are delegated by the team leader then a person is made responsible to perform one particular task. On the bridge of a ship the master needs to make sure the tasks are delegated properly to be sure that the whole operation is performed safely. In busy periods this is very difficult to manage and if tasks are not delegated properly omissions will happen which will lead to a crisis situation developing [27]. On port approaches, tasks are delegated to various team members, for instance whilst OOW1 is looking after the navigation of the ship and plotting positions, OOW2 is tasked with dealing with communications, the helmsman is designated to steer the vessel, the lookout is performing lookout duties, and finally the master has overall command.

Initial crisis management

A crisis is a situation that materialises unexpectedly requiring decisions to be made under pressure and within a short period of time. In a crisis situation the sense of loss of control builds quickly and routine tasks become increasingly difficult. The leader should be able to identify specific threats and respond accordingly.

There are some initial procedures given in the Bridge Procedure Guide for the expected emergencies on ships such as steering failure, engine failure, collision, grounding, flooding, man overboard etc. Doubt is a particular indication of a crisis and a good watch officer must be able to identify the cues that a crisis is building. An example of this could be that two methods of position fixing e.g. the Global Positioning System (GPS) and a position obtained by radar ranges providing significantly different positions.

C. Situational awareness (SA)

Endsley [28] defines SA as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."

It has been widely established and accepted that SA is a contributory factor to many accidents and incidents in high reliability safety industries [29, 22]. The importance of situation awareness in assessing and predicting operator competence in a complex and stressed environment has become increasingly apparent. Many accidents [30] have happened due to loss of SA such as the one described below.

During the evening of 11th February 2011 MV Boxford collided with fishing vessel, Admiral Blake, in the English Channel while on passage from Antwerp, Belgium to Gioia Tauro, Italy. The accident happened at 1839hrs when the chief officer went to check container lashing on deck and left the master in command. The master was busy checking the emails, discussing room repairs with a fitter and checking log entries of fire and boat drills. The deck cadet was performing lookout duties and reported a fishing vessel crossing from the starboard to the port side. The master was overworked in the last thirty six hours and had misinterpreted the situation as the fishing vessel was being overtaken. So he only altered ten degrees to starboard and returned to discuss the repairs. But later his vessel collided with the fishing vessel with no casualties [31]. This accident is one of many accidents that happened due to loss of SA.

Awareness of bridge systems

Active knowledge of the mode and state of bridge systems, including, but not limited to: Radar, Automatic Radar Plotting Aids (ARPA), Electronic Chart Display and Information System (ECDIS), Global Positioning System (GPS), Echosounder; needs to be maintained. Any changes in the systems' state need to be considered such as an unexpected depth from the Echosounder or the unexpected appearance of a land feature on the radar (Flin *et al.*, 2003). In the case of the Royal Majesty grounding the bridge team members failed to recognise the GPS position failure due to a faulty antenna for more than thirty four hours. The Chief Officer, navigating officer and second officers were plotting GPS positions based on the DR (Dead Reckoning) position during that time. The echo sounder alarm settings were not changed from harbour settings of zero metres and hence did not warn of the problem in advance [32].

Awareness of external environment

The Officer of the Watch is required to have active knowledge of the current and estimated position of the ship, weather information and traffic. This information must be shared among other bridge team members and necessary action needs to be taken to prevent consequences [14]. MV Maersk Newport sailed from Le Havre for Algeciras on 10th November 2008 into force nine winds with rough seas. Despite the forecasted poor weather no specific weather checks and measures had been carried out. The port anchor chain lashing arrangement failed because neither the extra lashing arrangements were fitted nor was the windlass brake sufficiently tightened [33].

Awareness of time

It is important that the Officer of the Watch has a sense of available time. This must also go hand in hand with them thinking ahead to consider future conditions and necessary contingency plans (Flin *et al.*, 2003). In a collision avoidance scenario, the rules (International Regulations for Preventing Collision at Sea) state that action taken to avoid collision shall be made in ample time. In a collision case between MV Hyundai Dominion and Sky Hope, watch officers of both ships spent valuable time on arguing the responsibilities of the action by the text messaging facility on AIS until finally they passed each other at a range of 0.2 nautical miles [34].

Situation assessment

Situation assessment is the evaluation and interpretation of information obtained from different sources (including but not limited to ship's position, course, speed, radar traffic, weather). After conducting a proper situation assessment of a changing situation, bridge team members must be able to recognise possible future problems. On 17th October 2006, the Maersk Dover, whilst en route from Dover to Dunkirk, passed just one cable astern of the Apollonia. The OOW on the Maersk Dover observed the Apollonia at a distance of 1.9 nautical miles at forty degrees on the starboard bow, only when he was called by the deep sea pilot on board the Apollonia. The OOW on the Maersk Dover did not do a proper situation assessment and initially made a succession of small alterations of course to starboard using the autopilot before eventually ordering the helmsman to begin hand steering and take action to manoeuvre to avoid collision [35].

D. Decision making (DM)

In aviation, Decision Making is defined as "The process of reaching a judgement or choosing an option" [14]. Although this definition is labelled as aeronautical decision making, this may be a universal definition for all high risk industries. Like an aeroplane pilot a ship's master also makes different types of decisions in different situations.

Decisions are dependent on various factors such as available options and support, crew qualifications and demands, company's standard procedures and policies for making decisions (ibid).

Problem definition and diagnosis

A decision maker should collect all the necessary information to determine the nature of the situation. Consider all explanations for the observed problem [14]. Onboard a ship, an example of a problem may be a close quarters' situation with various vessels at once or risk of collision or encountering fog in an area of heavy traffic. The first step for the OOW is to identify the problem and then generate the options for its solution.

Option generation

Option generation is a critical link in the decision-making process [36]. A decision maker, such as the Officer of the Watch, will need to generate several options before analysing each to make a decision. A decision maker will formulate different approaches to deal with the problem. This will depend on available time and information [14]. In a close quarters' situation in congested waters with various vessels at once, the OOW will generate the options for alteration of the ship's course or reduction of its speed.

Risk assessment and option selection

Risk is the probability that a relatively small hazard will develop into a crisis situation. A decision maker must evaluate the level of risk and choose the best available option to prevent this happening. If a close quarters' situation is developing, with various vessels in close proximity at the same time, the OOW will need to choose the best option from those available to avoid a collision.

Outcome review

A decision maker will consider the effectiveness of the chosen option against the current plan, once the course of action has been implemented [14]. Onboard a ship any decision taken by the officer in charge must be reviewed for the outcome. He or she will run a forecast simulation in his mind regarding the effectiveness of his decision.

IV. Data Analysis

Based on a review of existing literature and with the help of information collected through interviews performed with experienced seafarers, a generic decision making model, shown in Figure 1, was developed. The data collected was processed and a weight assigned to each criterion. This was accomplished using a mathematical decision making method called the Analytic Hierarchy Process (AHP).

A. The Analytic Hierarchy Process

Riahi *et al.* [37] used Saaty's [38] quantified judgements on pairs of attributes A_i and A_j represented by an n-by-n matrix D. In this matrix i, j = 1, 2, 3, ..., n and each a_{ij} represents the relative importance of attribute A_i to attribute A_j. This is shown in equation 1.

$$D = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \tag{1}$$

Having recorded the quantified judgments resulting from the comparisons of pairs (A_i, A_j) as the numerical entry a_{ij} in the matrix D, what is left is to assign to the n contingencies $A_1, A_2, \dots, A_n$ a set of numerical weights $w_1, w_2, \dots, w_n$ that reflect the recorded judgements. These weights $w_1, w_2, \dots, w_n$ can be calculated using equation 2, where a_{ij} represents the entry of row i and column j in a comparison matrix of order n:

$$\omega_k = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{kj}}{\sum_{i=1}^{n} a_{ij}} (k = 1,2,3, \dots, n) \tag{2}$$

The weight vector of the comparison matrix provides the priority order but it does not confirm the consistency of the pairwise judgements. Fortunately, AHP provides a measure of the consistency of the pairwise comparisons provided by way of a Consistency Ratio (CR) [37, 38]. The CR value is calculated according to equations 3, 4 and 5 where *CI* is the Consistency Index, *RI* is the average random index (Table 2), *n* is the matrix order and λ_{max} is the maximum weight value of the *n-by-n* comparison matrix D.

$$\lambda_{max} = \frac{\sum_{j=1}^{n}[(\sum_{k=1}^{n} w_k a_{jk})/w_j]}{n} \tag{3}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

$$CR = \frac{CI}{RI} \tag{5}$$

The CR is devised in such a way that a value of less than 0.10 means the pairwise comparisons are consistent. The comparisons should be reviewed if the CR value is more than 0.10.

Table 2: Value of *RI* versus matrix order [38]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

B. Geometric Mean Method

AHP was initially developed as a decision making tool for individual decision makers. However, by using the geometric mean method the individual pairwise comparison metrics of any number of experts can be aggregated [39] Experts' judgements can be aggregated using the geometric mean method identified in equation 6 where, e_{kij} is the k^{th} expert judgement on pair of attributes A_i and A_j.

$$\text{GeometricMean}_{ij} = [e_{1ij}.e_{2ij}.e_{3ij} \ldots e_{kij}]^{\frac{1}{k}} \tag{6}$$

C. Numerical example

The following numerical example of a single experts pairwise judgements shows how the AHP was utilised to establish the weights of criteria in the taxonomy (Situational Awareness, Decision Making, Leadership and Team Work).

$$D = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$$

A matrix was constructed to capture the pairwise comparison judgements of this expert. This matrix was populated with the data derived from their pairwise judgements:

	SA	DM	LS	TW
SA	1	1	1/3	2
DM	1	1	1	3
LS	3	1	1	3

TW	1/2	1/3	1/3	1

Weights of the main criteria were then calculated using equation 1:

$$\boldsymbol{\omega_1} = \frac{1}{n}\left(\frac{a_{11}}{(a_{11}+a_{21}+a_{31}+a_{41})}+\frac{a_{12}}{(a_{12}+a_{22}+a_{32}+a_{42})}+\frac{a_{13}}{(a_{13}+a_{23}+a_{33}+a_{43})}+\frac{a_{14}}{(a_{14}+a_{24}+a_{34}+a_{44})}\right)$$

$$\boldsymbol{\omega_1} = \frac{1}{4}\left(\frac{1}{(1+1+3+0.5)}+\frac{1}{(1+1+1+0.3333)}+\frac{0.3333}{(0.3333+1+1+0.3333)}+\frac{2}{(2+3+3+1)}\right)$$

$$\underline{\boldsymbol{\omega_1 = 0.207260}}$$

$$\boldsymbol{\omega_2} = \frac{1}{n}\left(\frac{a_{21}}{(a_{11}+a_{21}+a_{31}+a_{41})}+\frac{a_{22}}{(a_{12}+a_{22}+a_{32}+a_{42})}+\frac{a_{23}}{(a_{13}+a_{23}+a_{33}+a_{43})}+\frac{a_{24}}{(a_{14}+a_{24}+a_{34}+a_{44})}\right)$$

$$\boldsymbol{\omega_2} = \frac{1}{4}\left(\frac{1}{(1+1+3+0.5)}+\frac{1}{(1+1+1+0.3333)}+\frac{1}{(0.3333+1+1+0.3333)}+\frac{3}{(2+3+3+1)}\right)$$

$$\underline{\boldsymbol{\omega_2 = 0.297538}}$$

$$\boldsymbol{\omega_3} = \frac{1}{n}\left(\frac{a_{31}}{(a_{11}+a_{21}+a_{31}+a_{41})}+\frac{a_{32}}{(a_{12}+a_{22}+a_{32}+a_{42})}+\frac{a_{33}}{(a_{13}+a_{23}+a_{33}+a_{43})}+\frac{a_{34}}{(a_{14}+a_{24}+a_{34}+a_{44})}\right)$$

$$\boldsymbol{\omega_3} = \frac{1}{4}\left(\frac{3}{(1+1+3+0.5)}+\frac{1}{(1+1+1+0.3333)}+\frac{1}{(0.3333+1+1+0.3333)}+\frac{3}{(2+3+3+1)}\right)$$

$$\underline{\boldsymbol{\omega_3 = 0.388447}}$$

$$\boldsymbol{\omega_4} = \frac{1}{n}\left(\frac{a_{41}}{(a_{11}+a_{21}+a_{31}+a_{41})}+\frac{a_{42}}{(a_{12}+a_{22}+a_{32}+a_{42})}+\frac{a_{43}}{(a_{13}+a_{23}+a_{33}+a_{43})}+\frac{a_{44}}{(a_{14}+a_{24}+a_{34}+a_{44})}\right)$$

$$\boldsymbol{\omega_4} = \frac{1}{4}\left(\frac{0.5}{(1+1+3+0.5)}+\frac{0.3333}{(1+1+1+0.333)}+\frac{0.3333}{(0.3333+1+1+0.3333)}+\frac{1}{(2+3+3+1)}\right)$$

$$\underline{\boldsymbol{\omega_4 = 0.106755}}$$

The weight values were found to be 0.207260 (ω_1), 0.297538 (ω_2), 0.388447 (ω_3) and 0.106755 (ω_4). The Consistency Ratio was then calculated using equations 2, 3, and 4.

Based on equation 3, $\lambda_{\max}$ was calculated as follows:

$$\omega_{1x} = (1 \times 0.207260) + (1 \times 0.297538) + (0.333333 \times 0.388447) + (2 \times 0.106755) = 0.847790$$

$$\omega_{2x} = (1 \times 0.207260) + (1 \times 0.297538) + (1 \times 0.388447) + (3 \times 0.106755) = 1.21351$$

$$\omega_{3x} = (3 \times 0.207260) + (1 \times 0.297538) + (1 \times 0.388447) + (3 \times 0.106755) = 1.62803$$

$$\omega_{4x} = (0.5 \times 0.20726) + (0.33 \times 0.297538) + (0.33 \times 0.388447) + (1 \times 0.106755) = 0.43905$$

$$\boldsymbol{\lambda_{max}} = \frac{\left(\frac{0.847790}{0.207260}\right)+\left(\frac{1.21351}{0.297538}\right)+\left(\frac{1.62803}{0.388447}\right)+\left(\frac{0.43905}{0.106755}\right)}{4} = \boldsymbol{4.118196}$$

The mean value for λ_{max} was found to be 4.118196. If any of the λ_{max} values are found to be less than n (the number of criteria), which is four in this case, then there is an error in the calculation.

The CI is calculated based on equation 4:

$$\mathbf{CI} = \frac{\lambda_{max} - n}{n - 1} = \frac{4.118196 - 4}{4 - 1} = \mathbf{0.03939}$$

As shown in table 2, the Random Index (RI) for four criteria is 0.9. With this in mind, the CR value was calculated based on equation 5:

$$\mathbf{CR} = \frac{CI}{CR} = \frac{0.03939}{0.9} = \mathbf{0.04376}$$

The CR value for the main criteria was found to be 0.04376. A CR value of less than or equal to 0.1 indicates that the experts judgements are acceptable[38]. As a result, the consistency of the pair-wise comparisons conducted to establish the weights of the main criteria are acceptable. The same calculation process was followed to obtain the weights of each sub-criterion identified in Figure 1 and to check the consistency of the expert opinions used to generate those weights.

C. Knowledge Representation (Results)

Data was collected through interviews conducting with twelve experienced senior deck officers based both across the United Kingdom and in Malmo, Sweden. However, only eight participants' results were ultimately used as the CR values of the remaining four participants' weighting data demonstrated that it was inconsistent. Figure 2 shows the weights of all elements in the NTS taxonomy framework as determined from the results provided by the eight participants.

GOAL	CRITERIA	SUB-CRITERIA
Deck officers' non-technical skills	Teamwork 0.1914	Teambuilding and maintaining 0.2066
		Considering others 0.1860
		Supporting others 0.1831
		Communication 0.2436
		Information sharing 0.1807
	Leadership and managerial skills 0.2878	Use of authority and assertiveness 0.1579
		Providing and maintaining standards 0.0857
		Planning and co-ordination 0.1437
		Workload management 0.1280
		Prioritisation 0.1255
		Task delegation 0.1316
		Initial crisis management 0.2276
	Situational awareness 0.2863	Awareness of bridge systems 0.2433
		Awareness of external environment 0.2375
		Awareness of time 0.1860
		Situation assessment 0.3332
	Decision making 0.2346	Problem definition and diagnosis 0.2447
		Option generation 0.2069
		Risk assessment and option selection 0.2426
		Outcome review 0.3058

Figure 2: Deck Officers' Non-technical Skills Taxonomy (with weights)

V. Conclusions

This paper aimed to identify the NTS necessary for deck officers to effectively perform their duties on the bridge of a ship. To successfully achieve this goal a taxonomy of deck officers' NTS was developed. This was done by reviewing relevant literature and then conducting semi-structured interviews of experienced seafarers. Once the taxonomy was established, weighting data was collected to enable the weight of each factor in the taxonomy to be established through the use of the Analytical Hierarchy Process (AHP).

Although the taxonomy has now been established testing is required to see how it performs in the assessment of deck officers NTS in a simulated bridge environment. It is the aim of the authors of this paper to go on to compare the data collected through the subsequent assessment of deck officers to the traditional approach of the examiners 'gut feeling'. The similarities and differences identified are then to be analysed in greater detail in a subsequent paper.

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