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A Cognitive Work Analysis

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Toward Functional Augmented Reality in Marine Navigation: A Cognitive Work Analysis

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Abstract

Augmented Reality, (AR) also known as vision-overlay, can help the navigator to visually detect a dangerous target by the overlay of a synthetic image, thus providing a visual cue over the real world. This is the first paper of a series about the practicalities and consequences of implementing AR in marine navigation. A Cognitive Work Analysis is carried out to derive a scientific base for a functional interface that best supports navigators in their work.

1. Introduction

The task of the watch officer (WO) can be described as systems process engineering. Long periods of relative inactivity can suddenly change into a situation requiring heavy multitasking with a high level of workload. It is no surprise then that, based on the number of navigational claims, the Swedish Club has reported that in most accidents (69%), human error is an immediate cause. In this research, we focus on the prevention from accidents related to navigation, collision and grounding. From the same Swedish Club analysis it appears that lack of situation awareness is an immediate cause for collision (38%) and groundings (55%).

Although several measures like Vessel Traffic Service (VTS), separating traffic, and the introduction of electronic navigation have helped decrease the absolute number of accidents, the large annual number of accidents and dramatic loss of life motivates research into ways to further improve. Moreover, statistics in transported tonnage show that the amount of transported goods by sea has more than tripled since the 1950s and is expected to grow by approximately 2-3% per annum for the next decade *UNCTAD (2016)*. This justifies the effort spent on research and development to improve safety.

It is commonly accepted that technical malfunctioning of navigation equipment is seldom the cause of accidents, therefore focusing on human factors is opportune, however, the work routines of the navigator have barely changed over the last three or four decades. Morrel suggested already in 1960 that some form of expert aided decision support would be helpful in accident prevention, *Morrel (1960).* Despite several studies into this field, automated Collision Avoidance (CA) or decision support has still not been accepted. In the foreseeable future the human operator therefore remains the only entity to control the ‘open’ process of navigation.

The research presented in this paper aims at creating a novel interface that best supports the human in his or her role of decision maker. AR can contribute to this proposed Information Management Expert Support system. By superimposing a virtual image on the outside world, the reality is enhanced by visual cues. These cues can represent dangerous targets, however, in the E-navigation domain the functionality needs not be limited to CA alone. Using AR, we also expect to speed up effective information processing, although the practical implication of introducing this new technique is not at all clear. Although several ways to portray AR already exist, and although hardware development is ongoing, in this research we will use a Head Mounted Display (HMD) for testing.

An example of AR is shown in Fig.1 where the red projected box (c) points to a critical target, a red projected fence (a) shows the area to be avoided and a route suggestion (b) is shown by the projection of green 'runway' lighting. This projected information is corrected for the ship's attitude and motion and also takes into account the position and viewing direction of the observer.

Fig.1: Three examples of Augmented Reality

This paper is a condensed version in a series of papers on the introduction of AR in the maritime navigation domain. The first author is currently engaged in a PhD research into this subject. In his professional background, he has worked as a Maritime Officer, after which he has worked as a Nautical Cartographer at the Hydrographic Service of the Royal Netherlands Navy. Since 1998 he is lecturing Navigation at the Maritiem Instituut Willem Barentsz at Terschelling. The aim of this paper is to describe the development to obtain a scientific base for an interface that supports the navigation task. Future work entails to experimentally evaluate this interface in practice by experiments in a ship's bridge simulator. The scientific base will be developed through performing a Cognitive Work Analysis (CWA) *)* of the marine navigator, *Vicente (1999*.

2. Modelling the Marine Navigator's Work

2.1. Cognitive Work Analysis

Developments in the field of interface design and human performance modeling behold a promise of a novel approach. Rasmussen's taxonomy of Skill- Rule- and Knowledge based behavior suggests distinct levels of the skilled worker's performance and relates three different uses of available information, i.e., Signals, Signs and Symbols *Rasmussen (1983)*. One of the descriptions in his conclusion,

> *the tradition of designing interface systems based on one-sensor-one-indicator technology, where the operator is expected to 'figure out for himself' what the state of the system is based on indicator readings and training of system fundamentals*

can be regarded as typical for the 'modern' ship's bridge layout. Rasmussen suggests that the use of computer technology to optimize man-machine communication requires structured presentation of information according to the nature of the control task the operator is supposed to perform. Vicente highlights that 'open systems' by definition cannot be operated based solely on predefined rules and procedures because the designer cannot anticipate on the inherent richness of possibilities of these 'open systems'. Hence, the operator needs also information from the system that supports his task in solving unanticipated problems and situations. Bennet & Flach focus in their book on, *the primary purpose of an interface, to provide decision making and problem solving support for a user who is completing work in a domain*

In their book they adapt what they call a triadic approach, i.e., the design emphasis is put on the functional demands of the work domain *Bennet and Flach (2011)*. The underpinning Cognitive Systems Engineering (CSE) concept finds a broad ground, and from that the concept of Ecological Interface Design (EID) has been derived in the early 1990's *Flach et al. (1998)*. From Bainbridge *Bainbridge (1983)* we may infer that maximizing the use of 'perceptual motor skills' and minimizing the disruption of working memory may lead to a different balance in the distribution of mental resources thus supporting problem solving tasks.

The multitude of tasks that the watch officer (WO) has to deal with, are visualized in Fig.2. The navigation process of a ship can be characterized as dealing with a highly 'open' system, meaning that it is subject to unpredictable external and internal influences. Although ships are overwhelmed by Authorities', Class Societies', P&I clubs' and Fleet Operators' rules, requirements, procedures and checklists, the work cannot really be characterized as 'normative'. Which means that, although some of the tasks have been literally described in terms of instructions or checklists, the majority of work is done at the WO's discretion within the boundaries of safe and effective operation.

Fig.2 is a representation of many of these boundaries and can therefore be regarded as a constraint-based description of the WO's tasks, also known as 'task representation'. The quality assurance systems in use primarily describe the responsibilities of the WO but not 'how' to fulfill these. So when we analyze the work with the aim to develop an effective interface we should go further than this constraint-based task representation. The reason for this wider scope is that the work domain, i.e., the ship, its controls and its natural environment, have a huge impact on the operation. Thus, the work of the WO cannot solely be described by 'goals to be achieved', instead the possibilities and limitations of the work domain should be taken into account as well. And, as said before, the introduction of new technology, i.e., AR, requires us to design a new interface. The effectiveness of this interface heavily depends on the 'meaning' of the portrayed information, in other words, it depends on the provided or shown consequences, limitations and affordances of the system given its state and its environment. Therefore, we have to analyze the work domain, and use this analysis together with the task representation to come to an overarching framework in order to enable effective interface design.

2.2. The Work Domain

The work domain consists of ships and sea. A ship can be defined as a floating self-propelling controllable object, guided autonomously by a licensed watch keeper, with the purpose of undertaking a voyage expeditiously. In this context the sea can be defined as any stretch of water, deep enough to allow a ship to sail in and open for navigation.

Different from air navigation, traffic at sea is in principle unguided. However, there are situations where the risk of grounding or collision is deemed so high that precautionary measures are taken. In such cases the competent authority provides guidance by means of an established VTS or by arranging compulsory pilotage. The competent authority can only rule within its own territory. Outside territorial waters the principle of free sea rules since Hugo Grotius propounded this principle in his 'Mare Liberum' in 1609 *Grotius (1609)*.

Notwithstanding the principle of free sea, several arrangements have been accepted by international agreement in order to regulate shipping in international waters to enhance safety and reduce pollution. Amongst these are for instance the International Collision Regulations *IMO (1972)*. These 'Rules of the Road' focus primarily on the mutual conduct of ships. Ships have an obligation to act conformal to the Rules, the ship's flag state is the only authority empowered to keep the law on board a vessel sailing in international waters. The consequence of unguided shipping is that every vessel is free to choose and sail its route. Although this routeing is strongly biased by cost-efficiency, the wide diversity in ship types, ports of departure and destination results in an unpredictable, sometimes chaotic, traffic pattern.

On watch the WO has the responsibility to operate the ship within the boundaries of safety and efficiency and conform to the captain's watch orders. With the introduction of technical advances e.g., Global Positioning System (GPS), Automated Identification System (AIS) and Electronic Chart Display and Information System (ECDIS), the work of the WO has gradually changed. The classical bias on navigation, i.e., position fixing by taking bearings, deduced reckoning or sight reduction, has shifted towards observing the ship's progress on electronic equipment, i.e., ECDIS or its derivatives.

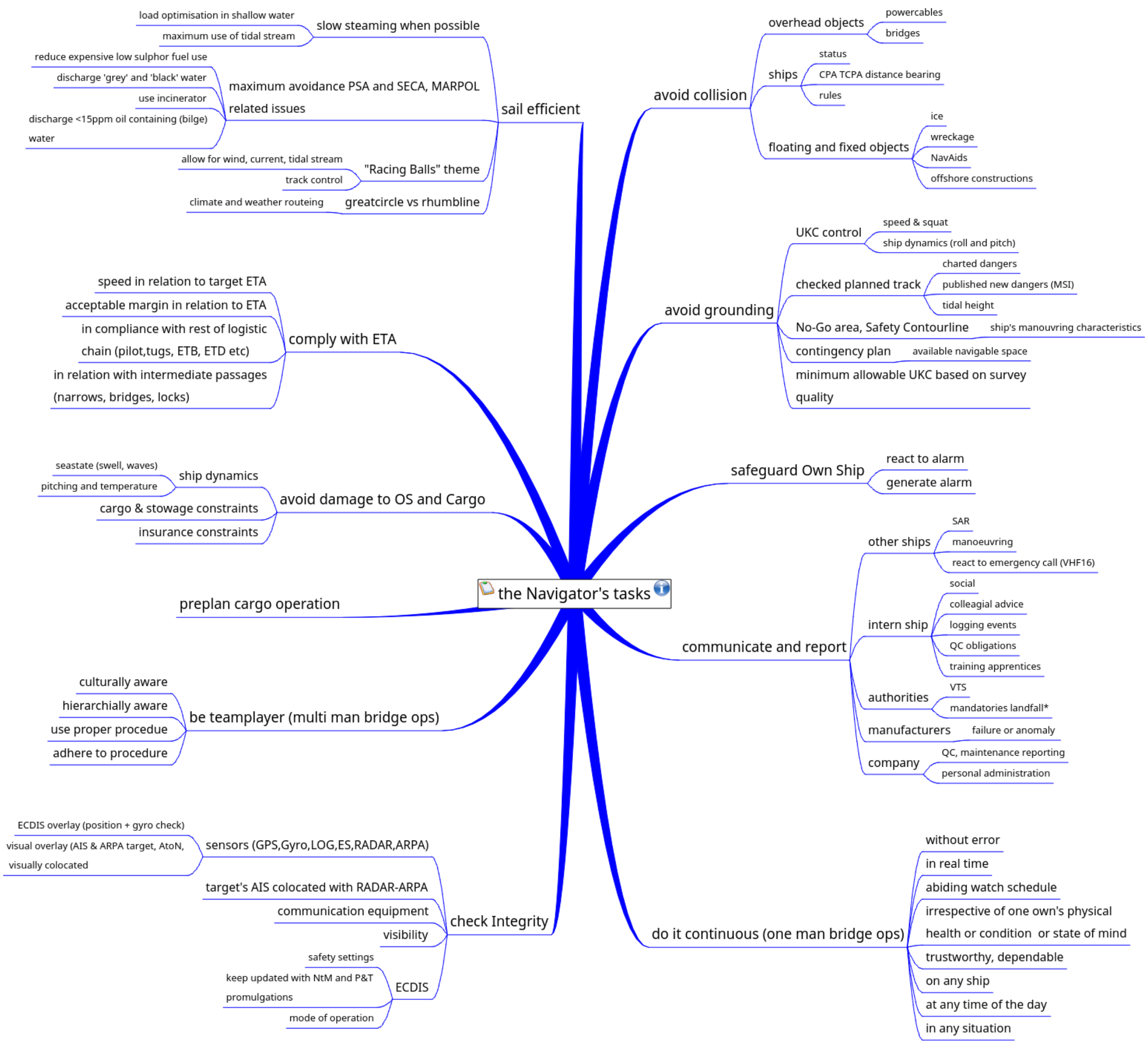

Fig.2 Constraint based description of the WO's tasks

In cases where the ship's autopilot is connected to the ECDIS the consecutive legs of the planned route are sailed without the WO's interference. This can be regarded as a basic instance of integration. Despite the claim of manufacturers that they offer integrated bridge design (IBS) and integrated equipment, real integration is not seen yet on most ships. It is the WO that does all the monitoring, integrity checking, decision making and execution. This 'human integrating' might be considered beneficial for building and maintaining Situation Awareness (SA). It can also result, however, in a wrong or impoverished determination of the situation due to fatigue and subsequent human limitations like, e.g., cognitive tunneling or negligence.

2.3. E-navigation developments in the work domain

The increase in the amount of worldwide transported goods by sea, the broadly felt public urge to reduce the environmental impact of transport in general, and the reduced cost of continuous world-wide satellite communication have led to the adoption of the E-Navigation concept by the IMO and IALA. The agreed definition of E-navigation is: *IMO (2017)*

> *the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment.*

An anticipated consequence of E-Navigation's safe communication possibilities is the exchange of the planned route ahead. An already materialized prototype is called “Intended Route Exchange”. This enables interacting ships to visually inform each other and even visually negotiate their planned maneuvering within a limited time frame of approximately 20 to 30 minutes *ACCSEAS (2015)*. This will lead to unprecedented interaction between ships. An interaction based on the exchange of the geographically referenced visualized planned route, and the visualized intention to deviate to avoid collision.

Without going into all detailed examples of the more or less matured E-Navigation prototypes, it is clear that the impact of these developments on the work domain will be tremendous. Whilst a materialized E-Navigation proposition has not yet emerged, nor has it been internationally agreed or adopted by IMO, we must focus on the existing work domain and keep in mind that within the next decade a drastic shift will be necessary due to the adoption of E-Navigation.

2.4. Decomposition of the Task Representation

It is obvious from the complexity of Fig.2 that, in order to analyze the total span of the WO's information needs, we have to decompose this task representation into subsets. The aim is to derive such subsets that every subset covers a logical cluster of tasks which each relate to specific information needs. From these information needs we can aggregate an overarching integrated interface which effectively informs the WO and supports him in the execution of this subset of tasks. Ultimately, the aggregation of each optimal interface should lead to an overarching interface design supporting the WO in his or her work spanning the task representation, Fig.2.

The following subsections deal with the subset of *CA*. This subset can be decomposed into three areas dealing with characteristic entities. All these entities are located on or above the sea surface, thus are, in principle, visible and do impose a real danger to the vessel. The three characteristic entities relate to the area of height restriction, e.g., bridges or overhead power cables, the area of other ships, and the area of passive objects. The other subsets, e.g., grounding avoidance, efficient sailing and damage avoidance will be covered in following papers.

2.5. Collision Avoidance, State Variables and State Dimension

In previous sections, we discussed the task representation of the WO, describing the boundaries within which she has to perform his work, or within which he has to keep the system that he's controlling. This system has its own characteristic and behavior which in its turn defines the possible outcome of control, or the possible states that can be controlled. The *State* can be defined as a vector in State Space describing the behavior of a system at a particular time. In the case of a ship this can be seen as the set of relative position, course and speed and status of the ship, wherein State Variables, such as course, speed, visual and oral declaration of the status and relative position can be used to describe this State.

The state dimension specifies the space of possibilities, a multidimensional space which can be regarded as the set of all Trajectories, hence, the description of all Behavior of a system over time.

The importance of describing the state dimension lies in understanding the intricate relation between the boundaries within which to control the system and the state of the system which initiates the need for control. The ship's State variables course and speed need not much explanation, both can be defined relative to the water as well as to the ground. The combination of the two can be used to predict the geographical position of the vessel.

The State Variable 'relative position' is used in relation to other traffic. This relative position has a consequence for the obligatory conduct of ships when they interact, thus, when risk of collision exists and ships are relatively close to each other. When the relative distance is large, however, ships are considered not to be engaged and both can voluntarily choose an evasive measure in order to prevent interaction at all.

The State Variable 'visual or oral declaration of status' applies to the special status that certain ships have in relation to their work, e.g., fishing, or limited possibilities, e.g., deep-draught vessels. The status of a vessel is made known to surrounding traffic by a visible daymark or light and can also be transmitted through marine radio by speech or by AIS-code.

2.6. Work Domain Analysis, Abstraction Hierarchy (AH)

The work domain of the subset CA can be described by two distinct hierarchies. The part-whole or decomposition hierarchy and the means-ends or Abstraction Hierarchy (AH). The former deals with zooming in or out on the work domain, thus either showing parts or the larger whole. The latter deals with relating structural means to achieve the higher-level ends, thus showing reasons for doing and ways to accomplish. A first version of AH for the task of CA is shown in Fig.3.

The scope, CA, is chosen because it is of paramount importance for safe shipping and has a strong relation with the introduction of AR as new technology in navigation. There is a relatively weak link with the safety related goal of grounding avoidance because the quality of the terrain, i.e., shallow or unsafe water, imposes a limitation in navigable space and therefore can have an impact on the CA work domain. For the sake of simplicity grounding avoidance is left out of this analysis. At a later stage this link will be revisited leading to an overarching integral work domain analysis for the worker. The generic term worker is used on purpose, and can be considered as the bridge manning varying from a team consisting of five professionals down to a single licensed watch keeper. Unmanned bridge operation is currently illegal.

The Functional Purpose is the highest level in the AH, it can be interpreted as the purpose for which the system is designed. Focusing on the nautical application we can state that a ship was designed in order to accommodate crew and cargo, stay afloat, fight fire and support its energy needs to name just a few. Of course the ship is also designed to propel itself to make progress and to manoeuvre to separate from traffic and objects, as well as designed for a specific height and or draught restriction. In this AH we discriminate three purposes that interrelate. The functional purpose of progress is carried out by means of the abstract functions direction and speed, which are carried out by means of the generalized function of Rate of Turn (ROT) and acceleration, respectively. These two functions are carried out by means of lift and thrust. Lift is generated by means of a rudder, and thrust by means of a propeller.

In this approach of maritime transport we analyze egocentric self-navigation applied to a conventional ship with one rudder and a single fixed pitch propeller. Existing variants like e.g., azimuthal-controlled propulsion, multiple propellers, bow-stern thrusters and active rudders are left out.

The other two functional purposes in this AH example are horizontal- and vertical separation. Both are dealing with CA, and relate to progress, i.e., direction and speed as well. Horizontal separation is carried out by means of a safe distance to a target, another ship, on the one hand, and on the other hand by means of a safe distance to an object, e.g., a wreck, buoy, rock or iceberg.

Vertical separation is carried out by means of a safe Under Keel Clearance (UKC) with respect to the ground and a safe Overhead Clearance (OHC) with respect to a fixed cultural object like an overhead power cable or a bridge. The reason for this diversion is the characteristics of the mentioned three object types and the different sources of information that are needed to plan for and take evasive measures. Justification for this motivation is given in the next three paragraphs.

The first abstract function deals with the safe distance to targets. We use the term 'target' as a generic name for active entities as opposed to objects which are passive. This function is carried out by means of the COLREGs and subsequently by means of the Own Ship's (OS) safety zone which on its turn is defined by means of the OS's particulars like length, breadth, speed, cargo, draught, etc. So, in order to keep a target out of OS's safety zone we apply the generalized function of the COLREGs to the end of complying with the rules, which can be applied by means of the abstract functions direction and speed. This illustrates the relation between the functional purpose of progress and horizontal separation.

The second abstract function, horizontal distance to objects, deals with objects in the water. This varies from charted aids to navigation, charted production gear like fish farms, dredge pipelines, wind turbines and Single Point Moorings to uncharted floating dangers like debris, ice or wreckage. The commonality is that these are passive objects usually in the vicinity of shipping routes, fairways and harbours, and that their existence is not always known, so their position may not be charted, and their actual presence is not always easily noticed.

Vertical separation can be realized by means of a safe UKC, which is realized by means of a sufficient difference between the depth of the fairway and the ship's draught which is realized by the vessel's displacement, the route, and date and time influencing tide and seastate. This in its turn is realized by means of the vessel's particulars, of which draught contributes most. Analyzing grounding avoidance is left for later papers.

The other means of realizing vertical clearance is a safe OHC, which is realized by means of a sufficient difference between the published safe height and the ship's air-draught. As well as UKC, this is realized by means of draught, tide and seastate.

The safe height of bridges and overhead power cables is found in nautical publications, i.e., Charts and Pilots, and depends on the height of the water level. The height of the water level is, to a certain extent, predictable, but can show unforeseen deviations due to the meteorological and natural conditions, i.e., wind, air pressure, river down flow. The other variable, the vessel's air-draught, is based on the vessel's dimension and present draught but is influenced by the ship's dynamics like squat, trim, list and rolling. Despite these invariants and uncertainties, the number of ships colliding with a bridge or hitting the bridgedeck with their superstructure grew to an average of three per year *Gluver and Olsen (1998).*

2.7. Control Task Analysis, the Decision Ladder

The Control Task Analysis (CTA) is complementary to the Work Domain Analysis (WDA). CDA aims at describing *what* needs to be done irrespective of worker or method. For this description the decision ladder, developed by Rasmussen, is used *Rasmussen (1987)*. This tool can be used to develop control task models and provides the necessary flexibility to allow for the shortcuts and shunts that experienced workers have developed over time in their strive to work effective and cognitively efficient. Fig.4 shows an example for the task of CA. A box means action, a circle means knowledge. Although action can start anywhere in the ladder, usually the detection of an object i.e., a bridge, ship or buoy will lead to a state of alertness or alarm and starts subsequent actions. Observations are made with independent, redundant, sensors to establish integrity of detection. From this, one knows that the detected object really exists and is in the detected position, so it's not an anomaly.

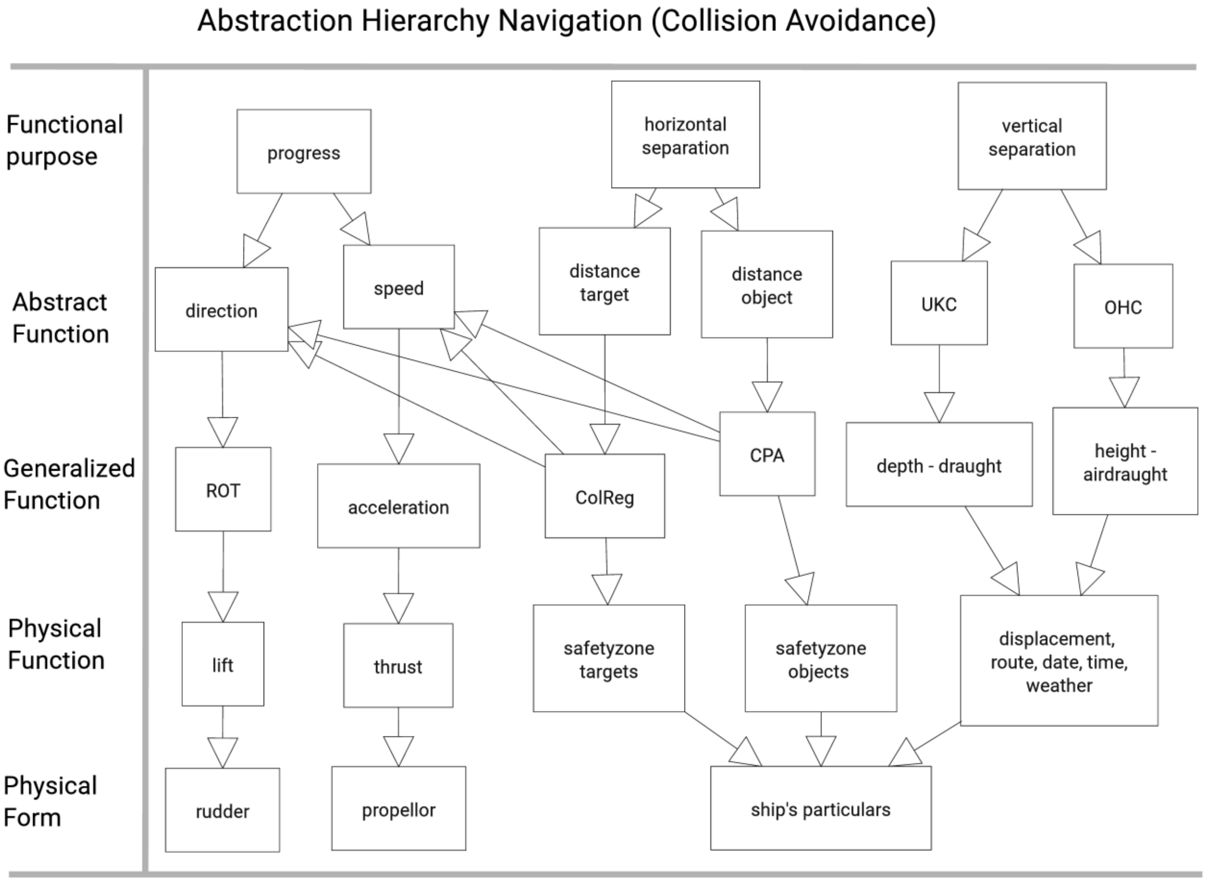

Fig.3: Abstraction Hierarchy Navigation and Collision Avoidance

Experienced workers can sometimes immediately recognize the situation from the activity of observation and take a rule based shortcut to the awareness of either the target state, the task, or even the procedure.

In case it's insufficiently clear to take a shortcut, the next step from the set of observations is to determine what the relation the OS has with the observed object; "Will the object come nearby and how can it affect OS's safety?". From interpreting the consequences of the system state it may be clear what the OS's target state is, however, when the situation is not recognized or unknown to the worker, he must follow the Knowledge Based Behavior loop and formulate alternatives (options), evaluate and interpret these until a satisfactory target state is known. With this knowledge of the OS's target state the worker can define a task, thus choosing to take evasive measures early on, or decide that the situation clearly relates to similar experience he had before. From this awareness of his task the worker decides what to do and under what prerequisite or condition he will maintain doing that action, thus, defining a strategy based procedure.

During execution of the procedure, feedback action is initiated through alertness for the situation and subsequent observing of sensors in order to become confident of the obtained safe system state. A shunt, different from the rule based shortcut, can be observed when the worker becomes aware of, or knows, one stage and associates this with the knowledge related to another stage, thus becomes aware of another stage. Such a shunt, or Associative Leap, for example can be observed between the awareness of system state and target state. An example is that the worker, becoming aware that the observed target is not an anomaly, but recognized rather as a buoy or floating object which is located in a position close to the bow of the vessel, immediately knows what the procedure is for action.

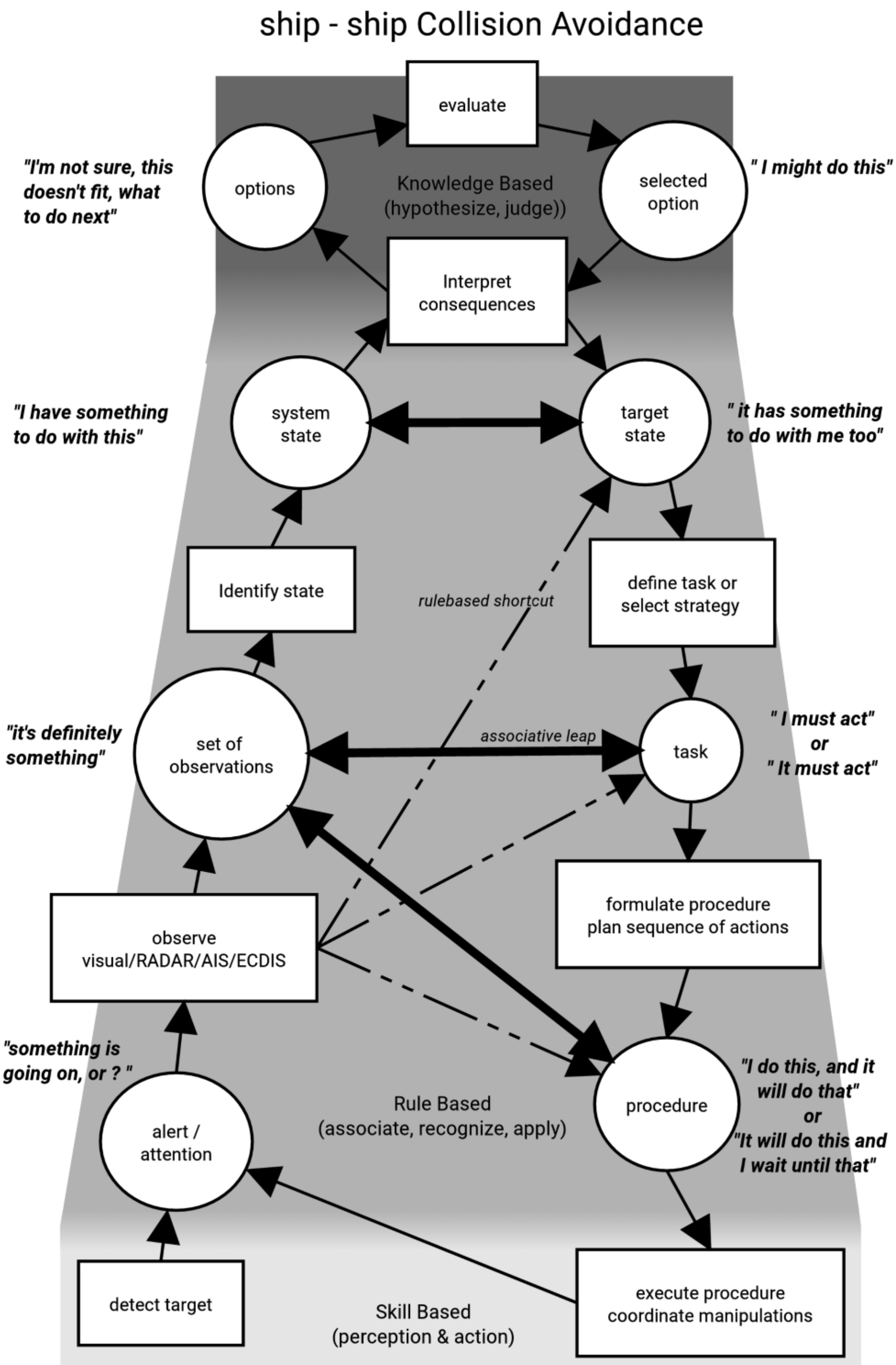

Fig.4: The Decision Ladder Ship-Ship Collision Avoidance

The categories of human behavior according to Rasmussen's SRK taxonomy are shown in the Decision Ladder by the Grey areas. The lightest shade of Grey, at the bottom, represents activities related to the lightest cognitive strain, the Skilled Based Behavior (SBB). Both target detection and the execution of a predetermined procedure is a rather standard task to perform, it interacts entirely with Signals and requires therefore little or no cognitive labor. In a distributed bridge organization these tasks are deployed by a lookout and helmsman, respectively.

The darker Grey area represents all activities and knowledge states that can be related with Rule Based Behavior (RBB). The related information can be regarded as Signs, which become meaningful by the worker's interpretation. This interpretation demands more of the worker's cognitive resources than SBB, but, as is illustrated by the Rule Based Shortcuts and Associative Leaps, the experienced Watchkeeper recognizes normal behavior in normal situations and shortcuts many steps in the Decision Ladder thus reducing his cognitive strain. Important in the design of a new interface is that these shunts must be recognized by the WO himself and the flaw of shunting too fast or too deep must be detected and re-iterated. The darkest shade of Grey is connected to the cognitive high demand of problem solving or, according to Rasmussen's SRK taxonomy, Knowledge Based Behavior (KBB). A typical example of this is noticing a real-life feature (e.g., a buoy) that is not charted. Several explanations are possible, of which some are relatively harmless, like observing a Waveheight Measuring Buoy at some distance abeam of the OS that is missed by a previous chart correction, while others might require immediate action like observing a wreck buoy ahead which is missed because the recently promulgated NAVTEX warning has not yet been noted in the Chart. In any case this needs serious checking, fault finding and observation in order to restore the navigation system's integrity. Even the experienced Watchkeeper needs all his knowledge, creative thinking and causal reasoning to do this in the limited available time. In the following papers, we will discuss the consequences this CWA has for the design of an effective interface.

2.8. Strategies Analysis

In the selected scope of CA we have analyzed the functional structure of this work domain where the worker acts upon. This is schematized in a model, the Abstraction-Hierarchy (see Section 2.6). We have also analyzed the actions that the worker performs to fulfill the task of CA. This is schematized in a model, the Decision Ladder (see Section 2.7). These two models are strongly interrelated, the actions 'what is done', are constrained by the domain that is acted upon.

From observing workers in this domain, it becomes clear that several ways, or strategies, exist and are being employed to reach the goal of safe sailing. The choice for a particular strategy is subjective and depends on the situation and the workload. A worker may apply different strategies to consecutive situations, he can also switch from one strategy to another while engaged in the same situation. Formal training provides usually one strategy that a worker employs at the beginning of his career. Experience, however, can expand the number of trusted strategies used by an individual worker. Apart from the taught strategy and the experience-driven strategies developed by the individual, much research has been conducted over the last five decades on alternative strategies for CA *Wilson Harris and Hong (2003), Zhao-Lin (1984).*

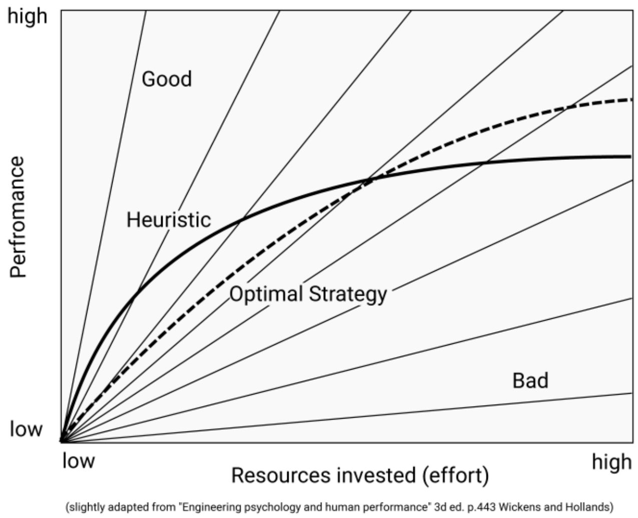

Fig.5 Performance Resource function

Wickens and Holland explain and illustrate, Fig.5, with the Performance Resource Function (PRF), why alternative strategies develop in the first place and that workers switch between them to perform their task effectively and efficiently. The Heuristic, seen as a mental shortcut that provides reasonable good performance without the investment of too much effort, varies greatly from worker to worker, but it also changes over time. For example, in the Netherlands the taught strategy for CA has moved, from keeping course and speed until engaged in a risk of collision situation, towards a more pro-active strategy where, with a timely slight alteration of course, engagement can at all be avoided. Apart from this, examples of strategies to give way in any situation (crossing ferries), or to claim right of way by VHF voice communication (AKA “Courseline Fetishism”) are reported by workers. *MARS (2017)*

In the maritime domain, the typical examples for display are RADAR/ARPA and ECDIS/GPS, sometimes superimposed onto each other and/or enriched by AIS information. The experienced worker has learned to interpret these two displays and use them to simulate and hypothesize on the developing situation. Thus building Situational Awareness whereupon he or she chooses for a trusted strategy.

Because several strategies already exist, these typical examples for display seem to be of no hindrance to the professional creativity of the worker. However, that does not mean that these displays are optimally supportive for the chosen strategy or to switch between strategies, neither does it mean that these displays support developing a Heuristic strategy. Therefore it is arguable that the task of CA in an 'open' system, is optimally supported by the aforementioned systems. Recent development in e-Navigation shows a prototype of “Tactical Exchange of Intended Route” as an example of the extension of RADAR, AIS and ECDIS. This example provides a way to visually share the intended route for the next limited interval of time and even negotiate about actions by visually changing the intended route and ask for confirmation. From the early testbed experiments we learned that workers adapt to this new functionality relatively fast and develop a, heuristic, strategy to use this new aid in their task of CA. In the latter example, it is important to understand that there hasn't been a strategy designed beforehand. Another important point is that the testbed users questioned the depiction of the displayed features and showed their concern about the anticipated workload on marginally vetted ships (e.g., coastal traders). This illustrates nicely the need for work analysis to be done in parallel with the introduction of this technically driven innovation.

Vicente suggests the use of an information flow map as a modeling tool with which to design dialogue modes *Vicente (1999) pp.224-234*, thus resulting in a specific designed display to support actor independent strategy. Assuming that strategies indeed can be generically used, justifies the research into, and development of information flow maps partly based on known strategies, partly based on yet undeveloped strategies thus supporting the user in dealing with the unprecedented event in the open system. One example of each information flow map is discussed in the following paragraphs.

For simplicity, the Information flow map for CA is limited to ship-ship encounters. In a following paper more complete analysis of the information flow will be used to design the dialogue modes mentioned before resulting in a display design.

Irrespective of the experience of the individual worker, or the team, and irrespective of the work domain itself, and irrespective of the actions on the work domain as well, the information flow constitutes of invariant sources and information retrieved from these resources as well as cues derived from the retrieved information. An example is shown in Fig.6. There can be automation involved, e.g., the Automatic RADAR Plotting Aid (ARPA) which provides a concise report about the detected target comprising of CPA, TCPA, true Course and true Speed on the basis of target following and the OS's course and speed. Also the received AIS message of the target, comprising of position COG and SOG i.a., can be used to calculate CPA and TCPA automatically. Without automation, risk of collision can be determined by observing the change in visual bearing, after which visual reconnaissance is needed to determine eventual action. In all cases multi-sensor identification and confirmation is desired to enable an integrity check of the used systems. During engagement with the target, a constant interchange of information and derivation of cues is entertained in order to maintain safety and eventually decide to initiate, alter or adjust the determined action.

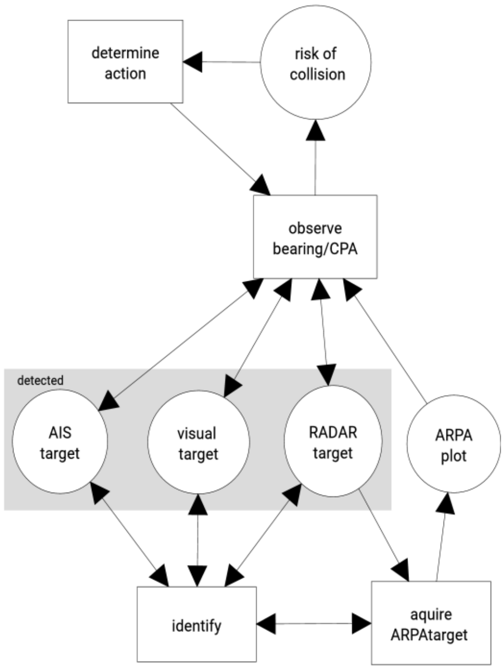

Fig.6: Information Flow map Conventional Approach

In the conventional bridge configuration, the worker integrates the retrieved information and searches for cues in order to build SA whereupon he can act. This human integration is supported to a certain extent by accepted automation like ARPA and AIS and their inferred alarming. Despite the fact that the concept of Maritime Collision Avoidance System (MCAS) was already introduced 50 years ago *Morrel (1960)*, Automated Collision Avoidance Systems (CAS) have still not been accepted by the marine industry for various reasons.

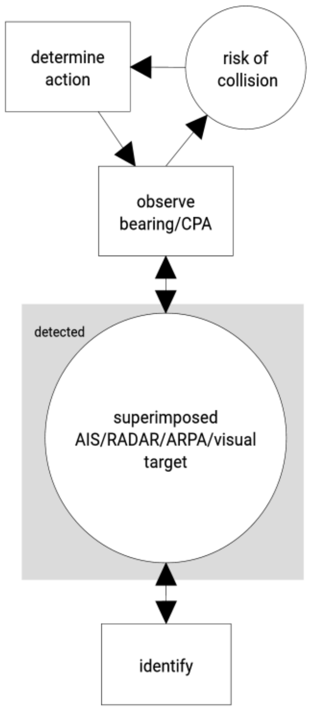

Fig.7: Information Flow map Augmented Reality

As said before, the introduction of new technology, like AR, requires careful rethinking and redesigning of the work process and its inherent information structure. This will have an impact on the information flow map, and to a much lesser extent on the work domain and control tasks. The impact on the latter two can probably be determined only after completion of the work analysis.

The Information Flow Map incorporating AR is sketched in Fig.7. The main difference between this suggested Information Flow map introducing AR and the conventional Information Flow map is that the identification is done implicitly by superimposing the AIS and RADAR/ARPA target on the visual target. On one hand this solves integrity question, because a co-location of AIS/RADAR/ ARPA markers and the visual target implies proper functioning positioning systems on both ships as well as a proper functioning heading system on the OS. This implicit identification and integrity solving reduces the cognitive load of combining and integrating two displays and the outside world.

On the other hand, however, it may as well increase cognitive load because any mismatch in the superimposed targets e.g., due to each of the position systems, or a shift in RADAR cross section, or an incorrect gyro will be noticeable and probably lead to problem solving behavior which might even distract the worker from a higher target i.e., noticing a possible risk of collision. Therefore, careful design and empirical testing is necessary.

2.9. Social-Organizational (leading to role allocation, organizational structure)

As already mentioned in Section 2.7, the worker is regarded as a varying entity. It varies from the individual WO, up to a bridge-team consisting of perhaps five, i.e., Captain, Pilot, Mate, Helmsman and Lookout. Rasmussen identified six criteria for dividing work demands, all of them are applicable to the maritime work domain *Vicente (1999) pp.254-255*. The normal situation, however, is that the bridge is operated by a single WO during daytime, helped by an obligatory Lookout during dark hours. The latter can be regarded as the sixth of Rasmussen's criteria i.e., regulation compliance. Examples of the other five criteria are: The engineer called by the WO to fix a problem with machinery: actor competency; The Harbour Pilot carrying specialist local knowledge advising the Captain during berthing: access to information; The Captain intermediating with Deck, Engine Room, Pilot and bridge-team during berthing: facilitating communication needed for coordination*;* A helmsman responsible for course-keeping: work load sharing; The captain playing a supervisory role instead of the single acting authority: safety and reliability.

Porathe (2017) adapts Hollnagel's four stages of control *Hollnagel (2017)* with Wickens' model of Cognitive Resource Supply vs. Cognitive Resources needed *Wickens and Hollands (2000) p.443,* Fig.8 to a situation where, depending on the phase of navigation, i.e., Open Sea to Berthing, the single WO (Person 1) gets overloaded with the workload somewhere during the phase of sailing in Confined waters. Adding a second person immediately relaxes the workload of the team, however, as complexity increases during berthing, the team of two Persons can again reach a state of Workload overload. Hollnagel suggest four stages of Control. Strategic Control where the worker (one, two or more) can plan far ahead in time, partly because of the low level of complexity, partly because of the surplus of available cognitive resources. When, due to higher complexity, more cognitive resources are required the time horizon of planning is reduced leading to less efficient or even ad hoc decision making. This is called Tactical Control. If the workload gets even higher or the situation gets more complicated, it is called Opportunistic Control meaning that the worker barely controls the situation thus leading to ineffective or even useless attempts being made. The Scrambled Control Mode is characterized by blind trial and error performance with little or no correspondence between the situation and actions. In this stage the worker has practically no control because the margin to allow for preemptive and pro-active work is reduced to nil. From this we can conclude that control over the work process deteriorates with increasing demand for cognitive resources. We can also conclude that adding more workers enables strategic control over the more complex process like navigating in confined waters, thus enabling to plan ahead and prepare for contingencies. Automation can reduce the workload of the worker. Assuming Porathe's adaption is based on workers without any aid of automation, the introduction of automation will have an obvious impact on the Resources Supply versus Need diagram, by shifting the boundaries between the control modes to the right.

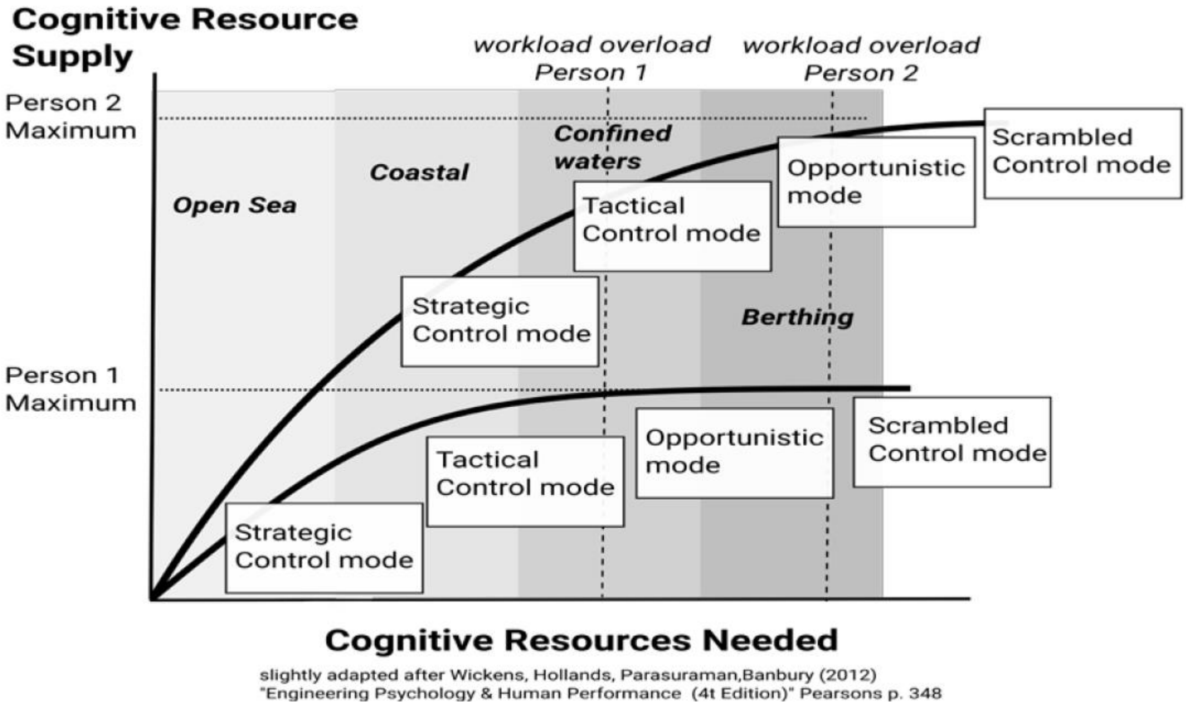

Fig.8: Cognitive Resources Needed versus Resource Supply

In practice, well accepted and applied forms of automation are the ECDIS and the Autopilot. When we schematize stages and levels of automation according to Wickens and Holland, ECDIS is a typical example of stage one,'Information acquisition and analysis'. The OS's GPS position is plotted on the Electronic Chart and checked against both the maximum allowed deviation from the intended route and the distance to the determined safety contourline. This is a high level of automation, it leaves practically no manual work for the WO. The latter form, the Autopilot, can be regarded as stage two automation, decision and choice. The level of this automation depends on the technical advancement of the autopilot fitted on board. The advancement varies from basic heading control, the lowest level of this stage, to an integrated system (ECDIS and autopilot). This system enables track control and curve control at Level 4 or 5, that is automatic action with human consent or unless human vetoes, respectively. It is much dependent on the individual worker's experience and trust in the system to what level he will employ this advanced possibility. A formative working practice on this automation has not been adopted, although the opinion that this should be done is advocated by some, e.g., Sagen hypothesizes in his article that the disaster with the Costa Concordia would have been prevented using such high-level automation like track and curve control *Sagen (2015)*.

More applicable to the focus of CA is a third example of automation, the Automated RADAR Plotting Aid, ARPA. This is clearly stage one automation, information acquisition and analysis. In general, ARPA is trusted as a primary information system providing several features of the tracked target up to a visual and audible warning for critical CPA. The level of automation is high, because manual intervention or a check on the plotting process is seldom done, which in few occasions has led to accidents due to misinterpretation or trust in wrong information.

Focusing exclusively on ship-ship CA, the mentioned examples of automation can be distributed over the abstraction decomposition and also over the decision ladder. The latter has the greatest impact on our analysis.

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