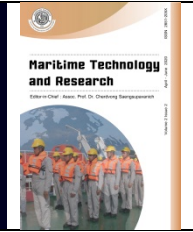




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Research Article

### A “Net-Centric” conduct of navigation and ship management

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#### Abstract

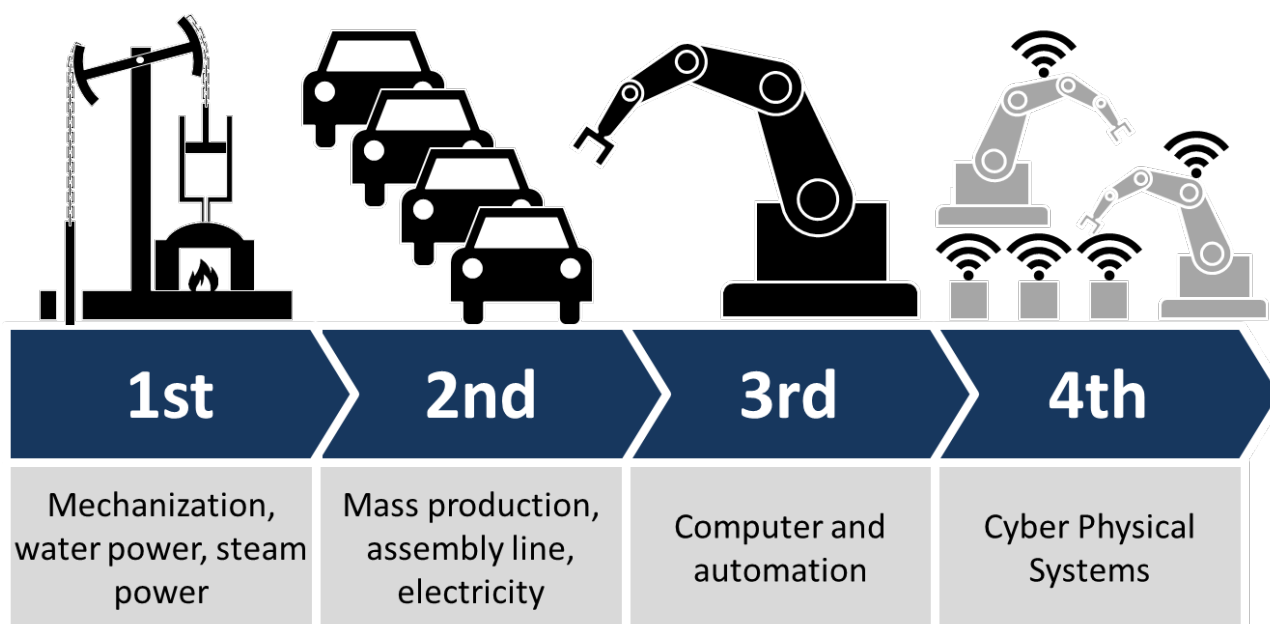
Following the so-called “Industrial Revolution”, the shipping industry has benefitted from a very extended number of technology innovations. Over time, shipbuilding practices and the equipment of ships have been significantly improved. Furthermore, during the last couple of decades, the continuous improvement and integration-interconnection of electronics systems (the “network-centric” approach), have created a new operating environment for shipping. It is therefore not a coincidence that recent discussions on digitalization and autonomous ships provide a disruptive picture of how this industry may be transformed in the near future. Contemporary sea-going vessels are equipped with various technologically advanced systems and are highly automated. Today, all systems supporting the conduct of navigation and the various information technology (IT) applications related to ship management activities are heavily reliant upon real-time information to safely/effectively fulfil their allocated tasks. The issues of connectivity and interconnection clearly stand out. It is important to assess how navigation will be conducted in the near future. This analysis is based on a qualitative methodology, and its starting point, which also serves as the necessary “literature review”, is to identify and briefly discuss a certain number of technological developments that follow the network-centric architecture and have been recently introduced as equipment appropriate for ships. Next, it will examine how interactive processes and applications, both on the shore side and onboard vessels, can facilitate a safer working environment for seafarers and allow personnel based ashore to have a better understanding of what is happening at sea, as part of explaining the so-called “net-centric” framework of operations. Another important aim is to evaluate these promising technological trends according to their capacity of adoption in order to promote efficient and safe operations within the extended maritime transport domain. An important conclusion is that a net-centric philosophy and associated software applications can truly break down any existing limitations and create a collaborative environment for people and “machines”, including remotely controlled unmanned vessels.

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## 1. Introduction

History testifies that there is a dialectic relationship between humans and technology. Following the so-called “Industrial Revolution”, the shipping industry has benefitted via 3 main ways: a) the introduction of steam power on merchant ships (mechanisation); b) an enlarged volume of goods to be traded and demand for raw materials, because of the increased factory output; and c) certain metallurgical innovations that also improved shipbuilding techniques (Duru, 2010). From that point of time and onwards, the equipment of ships followed a path of continual optimization. Additionally, during the last couple of decades, the continuous improvement and integration-interconnection of electronics systems (the “network-centric” approach) have created a new operating environment for shipping. Today, the issues of connectivity and interconnection clearly stand out for their influence upon human kind, with terms like “age of boundless connectivity” and “intelligent automation” being often used to describe our future world (Lehmacher, 2017; Dalaklis, 2018; Heath, 2018). It is indicative that a report under the title, “Transport 2040: Automation, Technology, Employment - The Future of Work”, which was recently launched by the World Maritime University (WMU), put forward the notion that: “*Technological progress and innovation have occurred throughout history and changed its course, for example the Industrial Revolution in the eighteenth and nineteenth centuries. Currently, we are about to embrace what is now termed the Fourth Industrial Revolution, which is characterized by the introduction of artificial intelligence, robotics, more and more interconnection, among other innovations*” (World Maritime University, 2019) (Figure 1).



**Figure 1** Different Stages of “Industrial Revolution”

Source: Christoph Roser (AllAboutLean.com)

The relatively new concept of “net-centric” operations has been defined by the United States (US) Department of Defence, as “*the ability for users to obtain the required information and applications **when and where they are needed***” (US Department of Defence, 2007). Considering that the concept “net-centric conduct of operations” quickly dominated the agenda of military affairs, it would be only a matter of time to transfer the same approach into the world of merchant shipping. In recent years, along with increased connectivity at sea, the prevailing engineering approach of integrating all the equipment and systems onboard sea-going vessels has created a

framework that the numerous sensors, computer systems and, most importantly, people conducting/supporting shipping operations (for example, seafarers onboard vessels and shore-based superintends, or people involved with provisions of vessel traffic services (VTS)) are all working together in what could be described as a “net-centric” collaborative environment, in order to increase situational awareness and promote safety at sea (Dalaklis et al., 2009; Bauldauf et al., 2018; About Sea Traffic Management, 2019). Optimizing the conduct of operations and boosting profits are also included in the same equation, via applying a similar concept in the shipping company’s working environment ashore. Very briefly, this new framework is based on the exploitation of the advances offered by modern information technology (IT) and telecommunications networks, to facilitate a better situational awareness level for all the people involved with ship operations and to significantly improve their performance.

Highlighting that the seas and oceans of our planet are now well integrated into the Internet (most often via satellite support), it becomes apparent that this global coverage has provided the necessary means for companies engaged with shipping activities to reduce costs across supply and demand chains, improve customer services, and even redefine their business-model/way of conducting operations. It is not a coincidence that modern ships are being transformed into “remote offices at sea”, with more reliable Internet availability; applications like voice over IP (Internet Protocol), email, and instant messaging are now used onboard contemporary sea-going vessels on a daily basis (Dalaklis et al., 2018, World Maritime University, 2019). Because of easy connectivity, interoperable platforms increase the possible interactive forms of cooperation among different users, establishing a collaborative working environment that maximises situational awareness. This collaborative environment comprises people, procedures, and associated technology applications, a fact that has caused the appearance of the alternative term “net-centric”, supposed to be more representative for highlighting the integration of people, instead of “network-centric” which is more appropriate to describe the issue of technical connectivity only. In any case, it is important to assess how navigation will be conducted in the near future. Following a qualitative methodology, the analysis at hand will discuss a certain number of technology applications that follow the network-centric approach and have been recently introduced as equipment appropriate for ships. Furthermore, it will investigate how interactive processes and applications, both on the shore side and onboard modern vessels, can facilitate a safer working environment for seafarers and allow personnel based ashore to have a better understanding of the developments taking place on vessels at sea. Finally, it will evaluate these promising technological trends according to their capacity of adoption to promote efficient and safe operations within the maritime transport industry.

## **2. Network-Centric service oriented architecture**

Historically, the first approaches concerning the exploitation of data exchange between interconnected equipment and systems onboard sea-going vessels relied on stove-piped architectures and applications. As a result, the outcome was fragmented/low correlated pieces of information in relation to what was really needed to carry out operations in the most efficient way. The reason behind this was the separation of information to individual systems, often being unable to communicate with each other. Especially for the people involved with the conduct of navigation, there is a negative impact on their level of situational awareness. For example, those navigating the ship need to access various different systems in order to gather all the “different pieces” of information available, considering the numerous sensors (RADAR, echo sounder, log, etc.) dedicated to delivering different tasks (Pallikaris et al., 2016). Even in the case that these systems were engineered with a clear focus to facilitate communication, this condition was in most of cases achieved at a later stage, with the initial approach concerning information secluded to stand-alone equipment. In the vast majority of those attempts to interconnect systems supporting the conduct of navigation, a restricted engineering approach limited connectivity to one pair at a time, instead of

evaluating the needs for the data and information exchange of the whole interconnected system (Norris, 2008; Norris, 2010).

During the 20<sup>th</sup> century, the prevailing approach for ships’ equipment and systems was focused more on the gradual improvement of pre-existent capabilities (Tetley & Calcutt, 2001), rather than on addressing “what exactly capabilities will be needed” to accomplish all the tasks under a holistic concept (Norris, 2008). Similarly, software-based capabilities were acquired and managed as relevant to stand-alone systems, rather than as an integral part of a network-centric environment. This condition resulted in different versions of software executing almost identical functions to different workstations, platforms, or subsystems (Testa, 2009). Gradually, the importance of “effective information management” was brought to the forefront of attention. However, during its first days, it was not mature enough to go beyond basic file handling and maintenance tasks that resulted in simple - low rate data flows between loosely coupled devices. Approaches of IT design in that era were still lacking today’s network-centric philosophy, thus prohibiting a system’s scaling, upgrading, and effective collaboration with other systems, in order to achieve a better level of interaction. Additionally, when bringing the issue of effectively managing-supervising ship operations from ashore into discussion, this previously described situation made it impossible to exploit valuable information across the 2 different working domains (onboard the ship and ashore).

On the positive side, it was rather quickly realized that a more flexible information management approach was necessary, in order to enhance information sharing and facilitate a collaborative environment that would be suitable for the needs of numerous different users. Today’s net-centric concept of operations apply to the way enterprises and organisations are planned to function, exploiting modern IT applications, which take advantage of the high connectivity available among different platforms, systems, or workstations, and allow extremely fast information exchanges via the widespread telecommunication networks. So, the concept of net-centric refers to a practice of leveraging communication and information technologies to establish an interacting collaborative environment throughout the whole extent of the enterprise, in order to create synergies and emergent capabilities in a synchronized way (Nanayakkara et al., 2009) and, above all, to serve well the needs of the various end-users (humans). The increased connectivity of network-centric configurations transcends existing borders between different systems, workstations, or platforms, trying to achieve interoperable connections between data, information, and applications that were not possible in the past. Integrating applications (and their relevant information) is the major enabler to create new innovative ways of leveraging decision-making effectiveness. If an enterprise (or a specific organisation, or just a single ship) is envisaged as a “system of systems”, a “service” is the fundamental building block (a piece of software and/or hardware) which performs a certain function within that enlarged system. All those individual services can then communicate via the established network-centric infrastructure, in order to execute all the necessary tasks to fulfil the system’s missions. A particular service could contribute to the achievement of more than one of the system’s missions, or just a small part of a specific task.

In that framework, a service can be considered as a simple “reusable component” that fulfils/realises business or mission tasks, scaling from a simple database lookup software application to a more complicated process, such as a mapping application, or even up to a complete Electronic Chart Display and Information System (ECDIS) in the case of a ship. To simplify things even further, many of various basic (or elementary) services together can be combined to create “advanced services”. Similarly, many advanced services together are usually combined to create the necessary “applications” serving the whole system. To establish a service oriented architecture, the methodology involved has as a starting point the definition of the necessary capabilities and tasks that the enterprise/organisation needs to possess, in order to fulfil its overall mission. In the next step, a functional analysis is performed, by thoroughly examining and describing what particular functions the enterprise needs to execute in order to possess all the aforementioned capabilities.

These functions are of course combined to create the “services” which will carry them out, either individually or in the form of “advanced services and applications”. Ultimately, the services definition stage signifies the transition from an abstract system’s functioning towards the respective technical architecture (achieved by a combination of software and hardware). This methodology is equivalent to the “divide and conquer” approach, where each of the system’s main functions is analyzed/broken down to more simplistic (elementary) functions needed to be executed (in parallel and/or series sequential combinations). The key idea is to discover flexibly suitable elementary functions- in the specific case services- which can be used simultaneously by various main functions. At the final stage, the overall architecture that brings together all services and applications to a networked infrastructure interconnecting and serving every possible user is defined (Dalaklis, 2004).

Therefore, the so-called “service-oriented architecture” is a way to constantly enhance information exploitation capabilities among different parts of a system. As mentioned above, after the basic/elementary services are defined as the primary building blocks, they can then be further combined to new, more complex services, adding functionality to satisfy more advanced operational needs. To sum up, a service oriented architecture is merely a technical philosophy, aiming to deliver information to the end-users across an enterprise or an organisation in more flexible ways by matching the technological solutions to the business and operational needs of the user, in this specific case, the mariner. Obviously, a service is recognised as a reusable component that reflects enterprise or mission tasks that exists as an independent functionality but can also be mixed with other services to support more complicated tasks and missions. So, each service can carry out/execute one or more operations or functions. In this sense, a service becomes a commodity. Service oriented architecture has become an increasingly popular mechanism for achieving interoperability between systems. It is a way of designing systems composed of services that are invoked in a standard way. Services’ reusability and expandability make possible their global distribution across organisations and their reconfiguration or upgrade to support new, more complicated tasks or missions (Dalaklis, 2018).

### **3. Elaborating on the Net-Centric concept**

Safe conduct of ship’s navigation and associated management activities constitute highly demanding and challenging “missions” in the contemporary era. High volume of traffic and congested sea areas are today the standard operating environment; modern ships have enlarged in tonnage and quite often carry dangerous cargos (UNCTAD, 2018). In combination with a strict regulatory framework of operations and very demanding customers, there is clearly a need to maximize efficiency- both on the ship side and ashore- to cope with all the requirements in a safe and secure manner (Dalaklis, 2017). Over the years, the further development of technology has clearly resulted into more complex ship structures, adding more and more machinery and navigation systems; all these in turn have transformed the decision-making process at sea into a delicate and complex issue. Moreover, decision-making aboard the ship is heavily influenced by dynamic patterns of collaboration and is associated with different levels of crew responsibilities (Bauldauf et al., 2016; Bauldauf et al., 2018). This team-working environment creates a requirement for information integration across the management, operational, and supporting processes scattered across many functional areas as different services. A potential solution can be found by using what was previously termed as “net-centric” philosophy in order to create a collaborative environment, where data and informational flows can lead to synergistic effects between different users. A net-centric approach towards operations onboard the ship can, if properly organized and exploited, maximize the tempo of operations and operational efficiencies, as well as improve the level of the ship’s safety.

Given that networking and telecommunications technologies keep improving, the net-centric approach to navigation and ship operations management is also expected to further increase

operational benefits, such as situational awareness and decision-making at sea, in the near future. Adopting to this philosophy is leading to new concepts of executing navigation and ship management activities, but it also implies new people skills, roles, and new organisational structures (Kitada et al., 2018). Onboard the ship, a net-centric informational environment will provide the mariner with more sophisticated and powerful tools to process and jointly evaluate high-quality data and information coming from a wide variety of sensors and other equipment. It can, therefore, improve agility in responding more quickly to navigational dangers and challenges. Extending connectivity and creating a network-centric architecture on the ship can facilitate the understanding, planning, and execution of a broad range of tasks, often working in close partnership with the shipping company’s personnel ashore. In fact, the notion of net-centric is further promoted if the shipping company, along with all its operating ships at sea, is framed as a “unified enterprise”. In this case, the net-centric approach should be viewed as an information management philosophy that effectively combines all enterprise’s technological and operational means to facilitate a better and more effective information processing mechanism and, as a result, contribute to an improved decision-making cycle. Therefore, the net-centric conduct of navigation and shipping management should not be limited to networking connectivity issues related to data and information telecommunications only but should relate to a concept of “business and organisational behaviour”, recognised as a strategic asset. The whole idea is to integrate people and all aspects of the available information and increase their speed of decision-making and execution (tempo of operations) due to the reduction of the necessary time, lasting from the initial point of data and information collection to the decision/execution of the necessary action (Bauldauf et al., 2018).

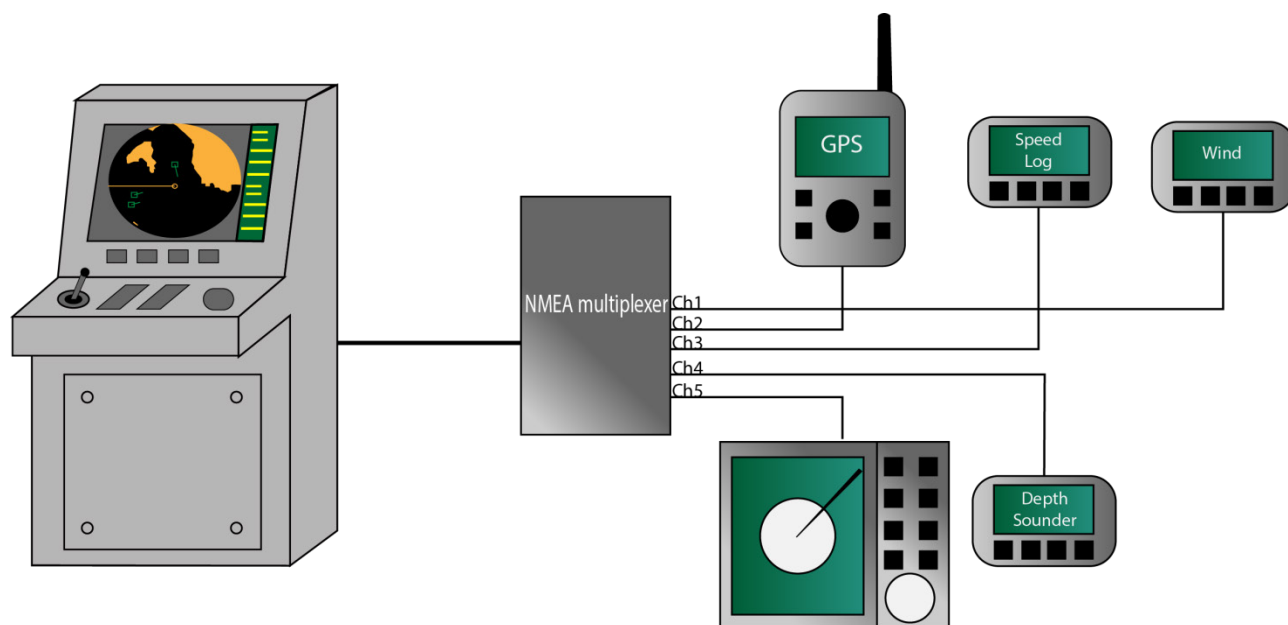
Trends in modern shipbuilding practices include more and more integrated automations, mainly in terms of combining equipment and systems supporting the conduct of navigation, systems used for loading/unloading, or those supporting control/monitoring of the propulsion plant machineries, and even those facilitating remote monitoring of ship’s environmental performance or executing maintenance tasks into a common net-centric informational platform (Nikitakos et al., 2018). Automation, mostly concerned with information processing hardware and software, is the fastest growing and most powerful influence on the engineering of modern systems (Kossiakoff et al., 2003). Data and informational exchange requirements are maximized, breaking the geographical limits of space within the ship (for example, providing the complete situation of the propulsion plant directly to the bridge) and even out of it, by extending exactly the same picture via a collaborative environment to the company’s staff ashore. In this interconnected framework, people that are clearly physically separated can work and interact as if being seated alongside each other, carrying out “together” all the necessary procedures and performing a specific operational or maintenance task.

More specifically, a more robust net-centric approach is achieved if all navigational and ship management processes are defined as workflows, consisting of specific functions supported by the delivery of services over networks. These interoperable services satisfy crucial mission-oriented capabilities and are invoked by the users through standard processes and procedures. Many services together combine themselves to advanced services and applications. Needless to point out, networks enable multiple users to share devices, data, and applications (network resources). The positioning and organisation of the different parts constituting the network and its workstations are relevant to the level of control over the shared information. Thus, networks allow people to manage or administer resources on multiple networked nodes from central locations. The use of networks drastically improves productivity. An indicative example for net-centric efficiency is mapping software. Its update to different workstations can be carried out with just a single command of “execution” in the case of that electronic charting information residing on a specific folder of a file server. Then, every querying workstation will have access to the common updated information. The lack of net-centric philosophy would require separate updates to the relevant folder of every console

or workstation using electronic charts. Moreover, more memory space would be needed in the later approach, therefore minimizing the efficiency of existing hardware.

#### 4. Network-Centric evolution and perspectives in ship operations

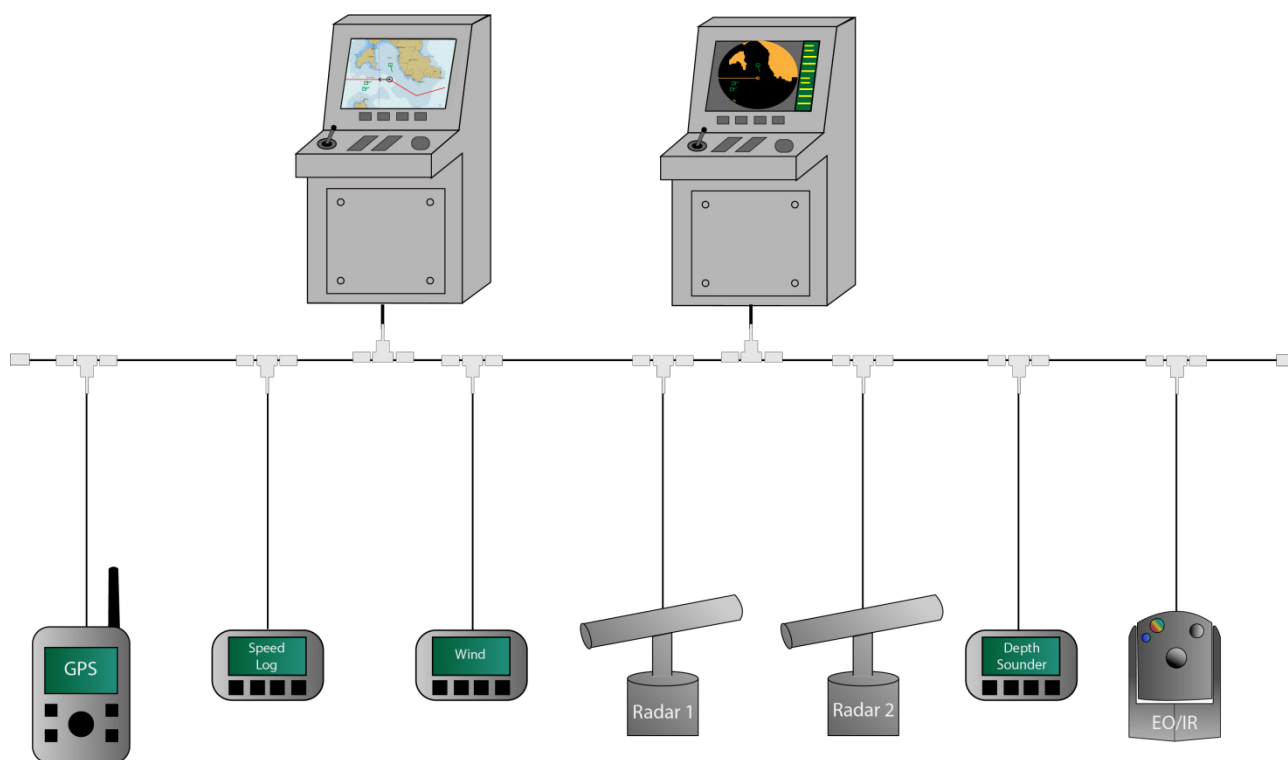
Historically, the first networking configuration applied to electronic navigational instruments and equipment was a very simple peer-to-peer network (West et al., 2016). In this peer-to-peer network, every computer can be configured to share some of its resources to the other computers by communicating directly with them. In very simple terms, for equipment supporting the conduct of navigation, the first applications consisted of a main (display) unit or personal computer positioned as a central device, with all the other instruments functioning as its peripherals by transmitting information to it, in a one-way communicational link (from the instrument to the unit). For instance, the input of the Global Navigation Satellite System (GNSS) involved the communication to the main unit of position, velocity, and time information, the gyro compass provided the course and rate of turn information, the speed log was responsible for velocity information, and so on. The protocol of the National Marine Electronics Association (NMEA) 0183 specified the particular format of the information, dividing it into specific packets of binary digits, necessary for the 2 communicational ends to understand each other. This simple protocol permitted the data transfer from a transmitting device to several receiving devices, also called listeners, in a one-way communication fashion, as described above. So, in order for 3 input sources (e.g., Automatic Identification System (AIS), a RADAR/ARPA and GNSS data) to be displayed on the same monitor, the hardware should include 3 input (serial or USB) ports to accommodate the 3 different in-coming signals. Further, the workstation’s software was responsible for the synchronization of the different data sources, a prerequisite for their proper processing. Unfortunately, the increase of connecting devices to the main unit resulted in data collisions among the various signal sources, prohibiting any of the “additional” data being read. A major upgrade was provided by a device known as NMEA 0183 multiplexer, which effectively combined the different signal sources to a single data flow, guiding it to one USB input port of the central device. **Figure 2** displays this kind of connectivity.



**Figure 2** NMEA 0183 multiple ports connection via multiplexer

Source: Created by Authors

This first configuration, though primitive, has contributed to the emergence of new ways to combine information into a single common display (creating a single point of interaction for the end-user) and has drastically improved the issue of situational awareness. However, the main disadvantage of this configuration is its lack of flexibility. As the number of possible connections increases, the main console is saturated, the information flow is perturbed, and the system will either stall or crash (Pallikaris et al., 2016). This is why the next generation of the peer-to-peer networking configuration permitted more dynamic, simultaneous two-way communication between any devices or workstations of the network. This new achievement resulted in a far more effective information flow and control at more workstations. This reflects the advent of the NMEA 2000 protocol, which permitted many electronic devices to be safely connected to a central cable-backbone functioning as the peer-to-peer connection bus (Pietak & Mikulski, 2009), as shown in **Figure 3**. In this case, the central backbone served as a single informational highway connecting all devices simultaneously, without requiring a separate cable for every possible connection. This added flexibility permitted any “connected” console or workstation equipped with a display to receive information by any possible sensor aboard, such as speed log, GNSS receiver, radar, AIS, depth sounder, shaft revolutions meter, engine temperature meter, gyro compass, etc. Also, numerous “additional” indicators could now be placed anywhere on board, as any new connection could be fed with the circulating information over the network.



**Figure 3** NMEA 2000 common bus connection  
Source: Created by Authors

As such, the transition from NMEA 0183 to NMEA 2000 provided the capability of 2-way data flow between any interconnected device. That is, any device could function either as a “transmitter” or as a “listener”. However, the connectivity and data exchange flexibility were still limited by the data rate and the common bus topology issue. In a bus network, the bus constitutes a single communication channel, like a one-lane bidirectional road. Consequently, flows in both



directions are possible, but not simultaneously. Every node that needs to transmit reserves the channel for its transmission to follow, with all other stations remaining in listen mode. To avoid data collisions, a communications protocol known as Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) is used. As mentioned earlier, when a node needs to transmit, it broadcasts through the bus an alert to the entire network, informing all nodes that a transmission is imminent. This access reserves the common channel (bus) for its transmission to be circulated. After the end of the transmission, the channel is free again. In the unfortunate case that 2 stations synchronize themselves in an effort to “reserve” the channel and emit simultaneously, a data collision occurs. On the positive side, an algorithm can solve this problem by obliging both stations to revert to listening mode and wait for a random time (different to each station) before attempting again to reserve the channel.

It is important to highlight the technological advantages, as well as the limitations, of this technical architecture. It is suitable for the connection of multiple sensors, indicators, and consoles only in the case that the exchange of information consists of small chunks of data, requiring transmissions of a limited duration of time. In fact, efficiency of the common bus technology diminishes as a function of the number of interconnected nodes and of how demanding a particular service is, in terms of data rate. For instance, a video tele-conference is a highly demanding service that monopolizes the transmission channel and necessitates a more robust networking configuration. Thus, due to the single channel (bus) limitation, the bus topology networks do not scale well. Even for the case of NMEA 2000, the more nodes are added, the more the network’s performance degrades in terms of data exchange speed and efficiency. Another disadvantage of the bus network is that it is not fault tolerant (not capable to continue functioning in the case of a damage or a malfunction). Evidently, a single break to the continuity of the bus affects the entire network (Pallikaris et al., 2016). This is why robust NMEA 2000 networks are installed with a double bus, to allow for the system’s uninterrupted functioning in the case that one of the buses is malfunctioning (increased level of redundancy).

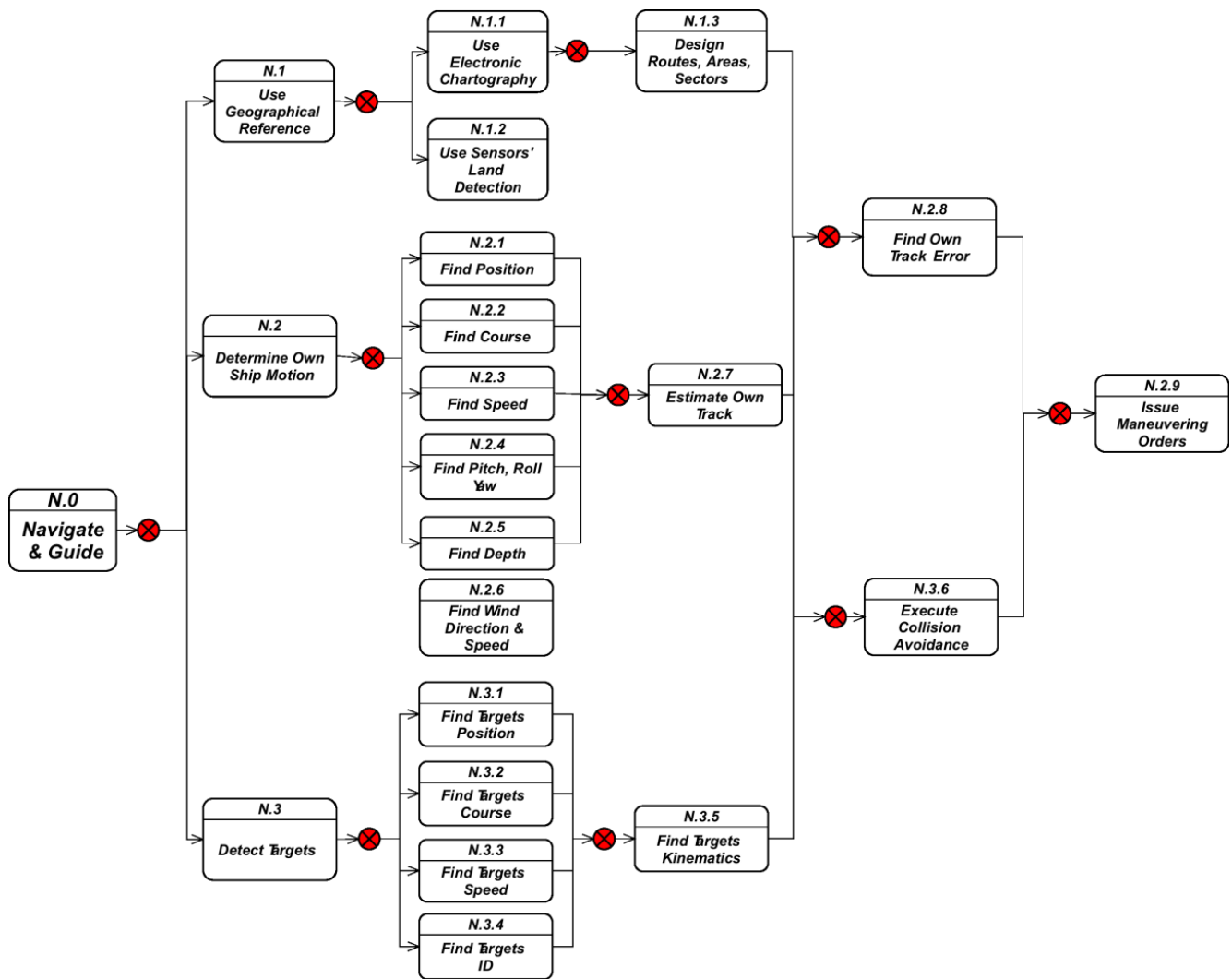
Today, the introduction of modern networking techniques and devices (switches, routers, and gateways), the use of flexible network topologies (bus, star, ring, and hybrid), efficient data and information handling provided by the client-server model and web-based applications supported by multiple interfaces, protocols, and software versions have revolutionized data flow, management, and co-processing capabilities. Converged network technologies are allowing new data transmission techniques, both cable and wireless; fast and accurate delivery of all types of content (e.g., data, files, email, video, audio) among interactive working platforms is now easily achievable (US Department of Defence, 2007). New data fusion solutions have emerged and data processing/evaluation from previously secluded sources is possible, even for users working at geographically distant locations. The new, more robust net-centric approach promoted the idea of shared services provided to the users, rather than in terms of predefined stand-alone equipment-systems such as AIS, ARPA RADARS, and ECDIS, to be connected at a later stage. This new approach considers the full spectrum of different functions or services that the user (the mariner in this specific case) needs to effectively and safely navigate his/her ship.

To understand how the modern net-centric service-oriented approach can shape the future of navigation and ship management, a simplified engineering top-down approach of designing a representative system will be used. Firstly, it is necessary to envisage the system as a whole, focusing on its mission objectives and the necessary capabilities to achieve them, avoiding sticking to known equipment and configurations of past solutions. Then, describing the system’s operation as a succession of interconnected functions will take place. These main functions will constitute the core processes (or core services) of the system, which gradually will expand to a multi-level span of functions. Using these functions, all the services, and their hierarchy and interconnections, will be specified as joined and interoperable building blocks. The system’s objective is defined as: “*To organize, co-ordinate and synchronize a shipping company’s activities (both on the ship-side and*

*shore-side), by using a net-centric seamless information exchange architecture, in order to establish a collaborative environment, able to maximize the operational efficiency, to improve the speed and quality of decision making and to ensure the safety of navigation”. For such a system, “indicative” core services are the following: A navigation and guidance service, a ship energy, propulsion and maintenance service, a cargo loading and monitoring service, a damage control service, and a logistics and supply service. To simplify the problem, the analysis will primarily focus on the “navigation and guidance service”, although its interoperable connections to the other main services will be briefly explained.*

The next step involves the conduct of functional analysis, aiming to specify the “Navigation and Guidance” core service’s functions which provide the necessary capabilities to execute proper and safe navigation. This analysis extensively captures and describes all the ship’s navigational activities through the workflow of functions needed to be executed. Under the so-called “systems engineering” framework, a function is recognized as a specific action or series of actions necessary to achieve a given objective, that is, an operation that the system must perform in order to accomplish its mission, or a maintenance action that is necessary to restore the system to its normal operational use (Blanchard & Blyler, 2016). For that purpose, the analysis is facilitated by the design of a functional flow block diagram (FFBD) which starts at its top-level, with the main processes (services) as its (top-level) functions. Then, the diagram expands with those top-level functions partitioned to a second level, and so on until the complete diagram is created, to the appropriate level of visibility necessary to identify all the services needed to carry out the functions. **Figure 4** summarizes the FFBD for the “Navigation and Guidance” service. These top-level functions are then analyzed to a multiple level depth which will provide a detailed understanding of the necessary services and their relationships to execute all these associated functions. In its most fundamental form, a service is a simple data set derived by a piece of equipment/system, such as the ship’s course, speed, position, roll, yaw, wind speed and temperature, and sea depth. The data related to the aforementioned services can be provided by many different sensors, such as GNSS receivers, 1 or 2 gyro compasses, one laser compass, and/or the digitized output of a magnetic compass. Each different device has its own advantages and deficiencies. The key idea is, instead of feeding individual data to different systems or consoles, to provide a unique, more robust ship’s “course service” to every querying console or system that needs the specific information to properly function.

Thus, all together, the outputs of the different sources can be mathematically combined with a suitable algorithm to a unique course service. This data fusion algorithm will combine the advantages of each source by dynamically balancing its contribution to the final result as a function of its accuracy and performance. For this purpose, the data from the different compasses and the GNSS course information can be forwarded to a navigational data and applications server where the data fusion operation will be executed. The server can then be accessed through the network from any workstation or system that needs this information. This way, the old approach of connecting specific instruments such as a gyro compass to a RADAR/ARPA console is obsolete. On the other hand, an elaborated course information, in the form of a virtual navigation sensor data, provided as a service to every possible connected node, can be delivered (as a service) to any navigational display of the ship. This architecture also provides increased fault tolerance because the service could be degraded but not “completely denied” in the case that one particular equipment/system malfunctions. In any case, the user could be appropriately informed about the malfunction and assume corrective maintenance and repairing actions.

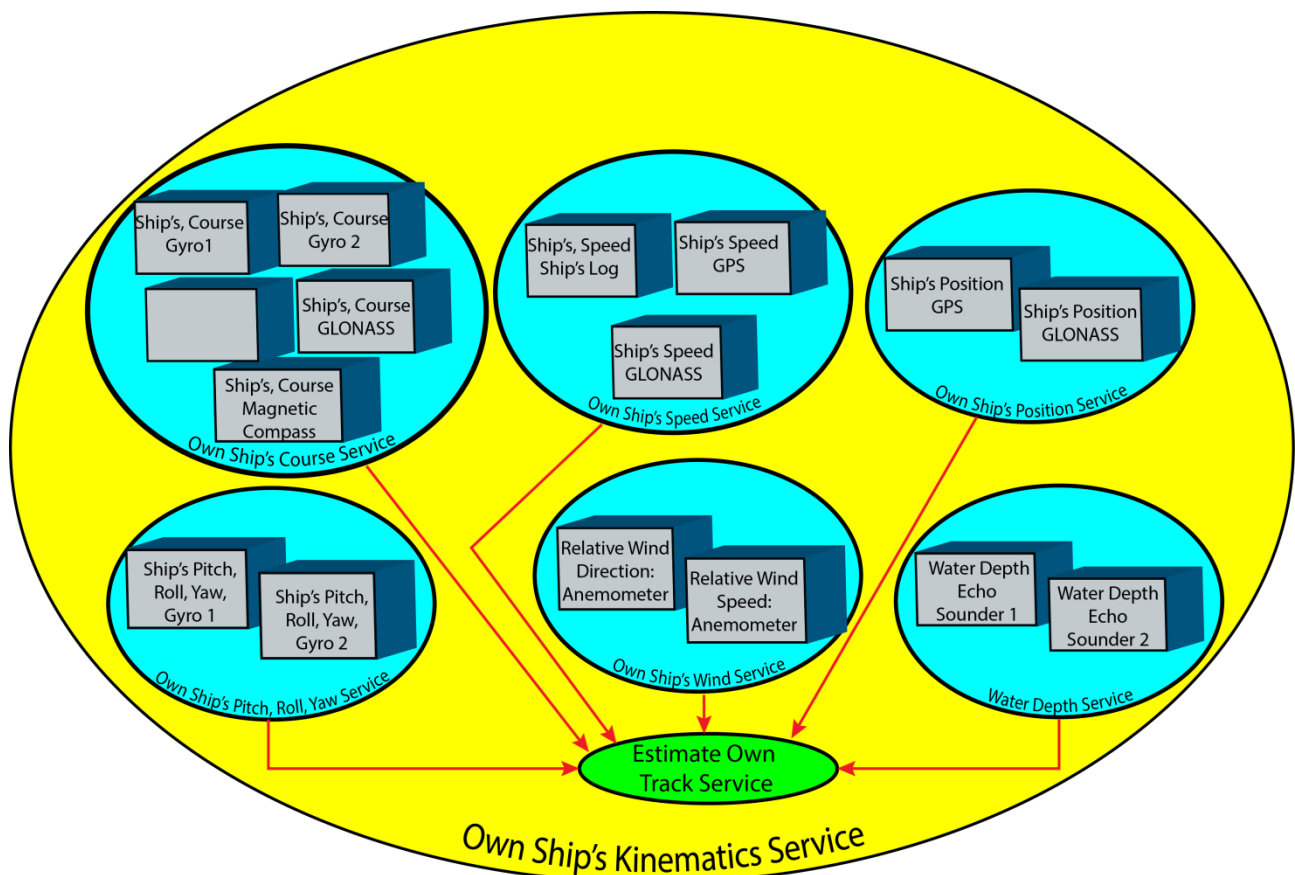


**Figure 4** Functional Flow Block Diagram for the “Navigation and Guidance” Service  
 Source: Created by Authors

The same principle applies to speed information, where a single “speed service” is provided by the server after the fusion of the relevant data provided, for instance, from 2 different ship’s logs and 2 GNSS receivers. Similarly, the available echo sounders data can be combined to a single more accurate output. A common “wind service” will also be included, to convert the relative wind direction and speed provided by the anemometer to their respective true values. To keep working with the services idea, another common service is “charting”. The common mapping sources are electronic chart folders, and the environmental information is usually provided from the ship’s radars (input from passive sensors, like the Electro-Optical/Infrared (EO/IR) devices- if available- can also be exploited). This information can again be collected to the navigational data and applications server and, further, forwarded to any bridge operator station which requires the specific service. A simple charting service will deal with the exclusive display of electronic chart cartography at different scales, combined with own ship’s position and movement service. A “sensors data service” could deal with the display of digitized radar or EO/IR image on a black background. A more elaborate “geographical service” could then perform the simultaneous display of electronic charting with the digitized sensors image overlaid, which permits checking of the cartography and position accuracy. To complete own ship’s kinematic information, 2 more services exist: the first, “estimate own track service”, is expected to use all the above kinematics information

to provide a full path prediction service. To this purpose, a Kalman filter can be used. This service is closely related to the “find route error service”. By communicating with the “route design service”, it is expected to compute the difference between the actual route and the planned/preferred route path. The outcome of this calculation can then be suitably fed to an advanced autopilot, translated to the appropriate rudder and propulsion plant orders to counter the effect of environmental forces, and bring the ship back to the desired track.

For the “targets detected”, the same net-centric service oriented approach will initially lead to different services for each separate track’s position, speed, and course. The targets data provided by each separate sensor and AIS should then be automatically (and/or manually) correlated to provide unique information for every target. Each target’s identity can also be verified after verifying the AIS information with the EO/IR camera’s image. Subsequently, the “target kinematics” service will precisely predict the estimated path for each target to follow. This informational organization of services can treat every workstation with a unified approach, since every service can be equally provided to any number of connected devices without the need to separately reintroduce it to every particular workstation. In fact, every workstation functions as a human-machine interface focal point, being able to perform any navigational function as selected by the user. The workstations no longer have definite roles but are assigned dynamic roles according to the user’s preference. Then, a more complex service called “targets kinematics service” will comprise all available targets information, related to their position, motion, and predicted track. Furthermore, a higher level service called “collision avoidance” could combine the information issued by the “own ship kinematics service” and “targets kinematics service” to propose the best evasive manoeuver to safely execute and avoid, instantly or sequentially, all prioritized targets, as shown in **Figure 5**.



**Figure 5** Own Ship Kinematics Service (with its encapsulated services and data)  
Source: Created by Authors

For the interaction between the user and the consoles/workstations, including the issuing of maneuvering orders, a “user interaction service” would be appropriate, to permit the user to effectively take advantage of the full system’s functionality and provide/authorize orders. Finally, a “display service” could be recognized as a “super-service” or application which combines all services to provide vivid visual information to the user through the selected monitors and indicators. An indicative architecture of such a system is as follows: There is a typical distributed backbone network (Dean et al., 2016) connecting the multiple sub-networks (or network segments) of a local area network (LAN). It consists of a number of routers connected in series. Each router is connected to a corresponding switch, with each sub-network’s devices plugged to the corresponding switch in a star networking topology. The local net communicates via a routing gateway with the external to the ship world, using satellite communications. Each one of the core processes (or core services) ensuring the ship’s operation constitutes a particular sub-network with its own server, containing the relevant data, services, and applications. The sub-networks communicate with each other through a combination of routers and switches. The improved connectivity can achieve any data or information flow between different servers, switches, and routers equivalently between every different workstation of the ship.

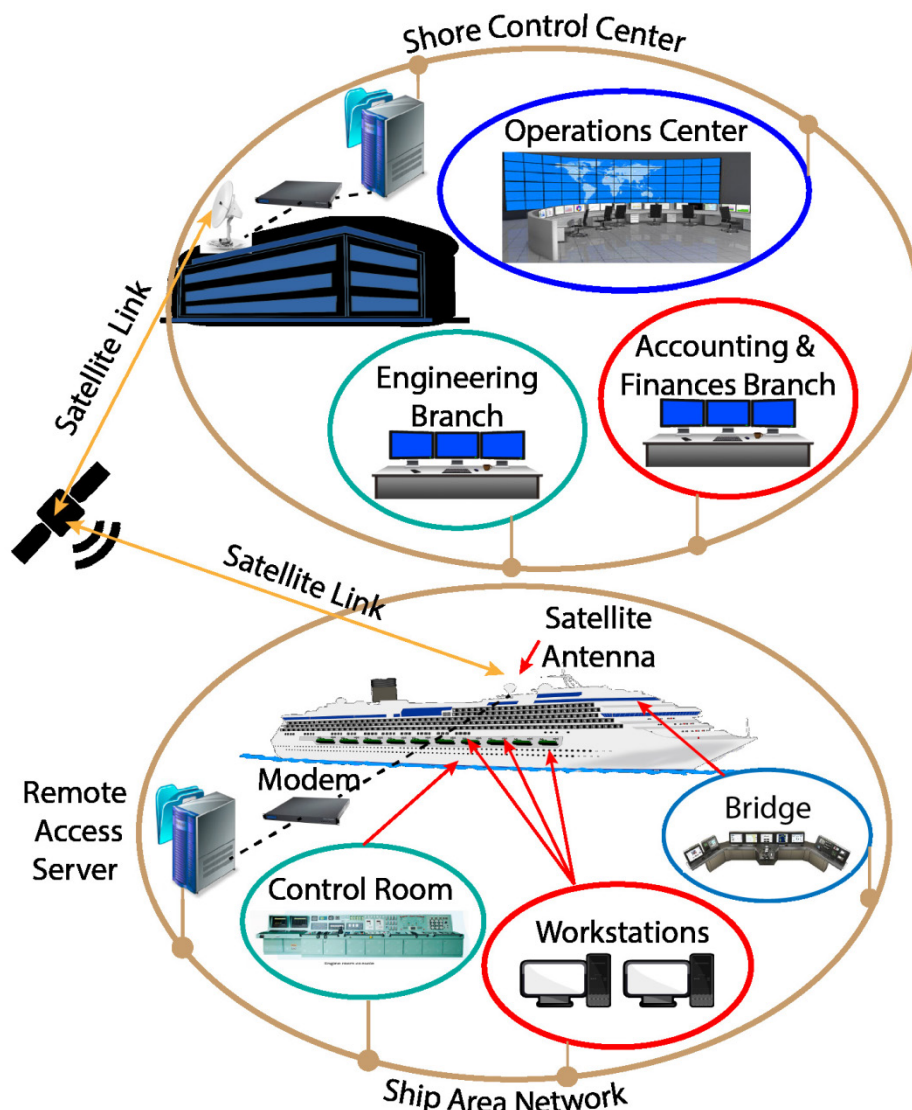
Moreover, at the technical level, the software of any particular sub-network can use the services of any other sub-network to construct a more complex own service. For instance, the engine shaft revolutions per minute and temperature and vibrations data can be fed not only to the ship’s control room server, but also to the bridge conning console or an alarm panel. The same principle applies to a propulsion plant monitoring service, which can be equivalently used by a control room or bridge workstation. Further, this data may constitute a part of the different parameters an algorithm may need to determine the exact ship’s motion and track. Such an algorithm may use the ship’s compasses, accelerometers, GNSSs etc., to predict the exact track followed by the ship and compare it with the pre-planned route that appears on the ECDIS and/or ARPA workstation’s display.

## **5. Net-Centricity onboard the vessel and ashore collaborative environment**

The net-centric collaborative environment literary breaks the ship’s geographical boundaries to include other critical stakeholders, including shipping companies, port authorities, people/facilities dealing with berthing, replenishment, medical, transportation and loading tasks, ship brokers, suppliers, agents, governments, and others. Thus, the net-centric approach can provide the joined information exchange platform that brings together on a constant interactive basis the shipping company, people involved onboard the vessel and ashore, and the company’s customers and suppliers. This approach makes it possible for people geographically (and administratively) separated to closely collaborate, as if they were positioned in the same office. This way, people and processes come together to accomplish particular tasks. Due to the networking connectivity advantages, a shipping company can create a relevant operations centre, specially designed for its departmental needs, to monitor and “command and control” all its ships simultaneously, as demonstrated in **Figure 6**.

By co-processing in real time all kind of information related to their voyage parameters, including machinery performance/fuel consumption and even prevailing weather conditions, the concerned company can relatively easily deduce every ship’s combined technical and financial performance and synthesize the total operational picture of its fleet. Different information levels can be selectively exposed on large format multi-functional displays according to the choice of its personnel, which will dynamically process all available information to take fast and accurate operational decisions in order to ensure the level of safety for the whole fleet and to maximize the associated profits. Putting forward a couple of alternative solutions, activities could include proposing the optimum travelling speed and route selection in conjunction with the more suitable bunkering ports selection, based on complete cost analysis of various possible choices. Taking

advantage of modern technology, the operations centre staff can dynamically reschedule the ships’ routes, renegotiate freights, conclude fast agreements with clients, and synchronize all supporting functions to its ships and personnel. Real-time position and movement of a ship could also be forwarded to a client, in order to explain to a ship broker the current company’s ship freighting capabilities, according to its ship’s operational status and availability. Technical assistance by experts can also be provided via video teleconference, in order to help the crew to restore a failing equipment. A more robust approach could include the continuous monitoring of critical equipment functional parameters and performance, in order to detect and predict malfunctions, prevent damages, and speed-up the repairing process. The whole maintenance monitoring of the ship can be executed from ashore, to respect timetables of planned or required maintenance surveys. The continuous measurements from the various sensors of a single equipment can detect a malfunction. Moreover, the measurements history and correlation from the same and/or different sensors can be used to predict malfunctions.



**Figure 6** Services onboard the vessel and company’s “Operations Centre”  
Source: Created by Authors

This function could also be correlated with the spare parts usage monitoring and availability for future resupply requirements prediction. Moreover, voyage performance statistics can be deduced, describing the freight costs as a function of cargo, fuel consumption, speed, and geographical and weather limitations. The performance of a vessel can also be evaluated, together with a timeline of maintenance interventions needed to correct main machinery and equipment degradation. Furthermore, the vessel’s budgeting system can also be supported or totally controlled from ashore, in terms of mutually processing with the responsible personnel onboard the ship all types of financial calculations, such as crew management payroll, running costs, and voyage budgeting. Also, by combining the company’s own information and records with the ship’s feedback, the human resources department can keep historical performance records for each seafarer, his/her family status, and date and period of embarkation, together with his/her particular qualifications and skills, in order to estimate his/her allocation or reallocation availability and evaluate the different possible choices (career management).

Connectivity with the port authorities and private agents can guarantee the on-time availability of spare parts and trained personnel for repairs during the next port visit, drastically reducing the necessary time for the ship to come back to its normal operating condition. Technically, the communication of a ship with the outer world can be realized via a remote access server (as previously mentioned). This server can not only selectively grant rights of access to its information and data, but also provide through its services remote control of parts of the ship’s particular equipment to the personnel ashore. The remote control of the ship’s equipment and activities capability can be extended towards the so-called “unmanned ship” (also, paving the way for autonomy) that is executing cargo transportation for commercial use. However, this not an easy decision to make, given the dangers of illegal actions, like hijacking the ship or hacking its network and, therefore, seizing its control. It is also necessary to factor in that the effectiveness of net-centric framework is not ensured unless all the people involved are well trained in the interactive information exchanging procedures. Summing up, using net-centricity organisational principles, a shipping company can achieve a high level of awareness within the whole organisation, boost its overall situational awareness, and improve its operational effectiveness/profits.

## 6. Conclusions

In recent years, the prevailing engineering approach of integrating all the ship’s equipment and systems has created a framework in which numerous sensors and computer systems and, last but not least, people, are all working together, in what is termed as a net-centric collaborative environment, in order to increase situational awareness and promote safety at sea. It is true that modern ships are heavily equipped, with numerous technologically advanced electronic systems available onboard. More importantly, all systems supporting the conduct of navigation, as well as the various information technology applications related to shipping management activities, are heavily reliant upon real-time information in order to safely and effectively fulfil the allocated tasks; the issues of connectivity and interconnection stand out. It is indicative the fact that increased levels of digitalization and automation onboard ships have already been impacting the work of both nautical and engine departments for more than a decade, with very indicative examples provided by “unattended machinery spaces” and “autopilots” supporting the conduct of navigation provision of remote assistance and operations by specialists located in shore-based service centres.

On a daily basis, ships of different sizes and capabilities carry vast quantities of cargo and a very large number of passengers cost effectively, cleanly, and safely. The objective of optimizing the conduct of shipping operations is clearly related to efficiency gains; it is a rather self-explanatory fact that an increasing number of technology applications and more automations onboard ships can contribute significantly to this objective. In the contemporary era, navigation and shipping management activities are increasingly carried out by net-centric organisational infrastructures. Moreover, legacy systems with what is considered as poor performance, and

proprietary solutions that do not meet the challenging/demanding operating environment at sea, are now being replaced by open, interoperable systems. Robust, resilient, flexible, and secure network solutions are bringing together every possible workstation onboard the vessel and ashore, to form collaborative environments that facilitate cooperation and promote synergies. Furthermore, the collaborative tools applied via the networked infrastructure enhance the decision-making process by enabling all parties to share and evaluate the same information at the same time. Access to all available pieces of information on a real-time basis can improve the issue of situational awareness and improve the tempo of operations. In fact, a net-centric model for the conduct of navigation and shipping management activities will help to seemingly move around all involved parts mission-critical information and to achieve information superiority that can be considered as an advantage over other competitors.

In summary, adapting the net-centric model of operations can be easily achieved for shipping. However, an intelligently designed and well organized net-centric architecture is simply an “enabler tool”. The shipping industry has already entered the era of digitalization, and an optimized flow of information by integrating different stakeholders, people at sea, technology applications, and processes should be viewed as a very crucial strategic asset for any modern (shipping) company. It is so expected/envisioned that companies will gradually move away from traditional working patterns, and towards a net-centric organisational approach, relying on intensive and efficient information sharing and availability. Modern ships are equipped with numerous technologically advanced systems and are highly automated. The on-going improvement and integration-interconnection of electronics systems, as well as advances in automations and robotics have already created a new operating environment for the shipping industry, with opportunities waiting to be reaped. A net-centric philosophy, and associated software applications, can truly break down any existing limitations and create a collaborative environment for people and “machines”, including remotely controlled unmanned vessels. While in the first case the benefits are obvious, in the second case the final form of the applications to adopt should be the product of serious (safety and efficiency) considerations. Gradually adopting, testing, and re-evaluating the expected technological breakthroughs can help to build the necessary confidence for effective “human-machine” interaction.

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