Conceptual ship design, general arrangement & integration of the human element: a proposed framework for the engine department work environment

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Abstract. Technological advancements and reducing crew numbers have contributed to evolving relationships between engine department operations and end-user demands. The work environment plays a crucial role in supporting the human element and should be considered throughout the design process of a new-build ship project. This investigation examined how end-user interests can be integrated early in ship development. A case study of a ship's preliminary general arrangement was used to map linkages between key engine department locations and equipment relevant for end-user tasks. The analysis revealed ship design deficiencies, which could negatively impact end-user logistics and functions if implemented in construction.

Keywords. Environmental design, link analysis, naval architecture, knowledge transfer

1. Introduction

The international shipping business is an expansive, competitive and globalized network influencing how vessels are financed, designed, constructed, insured, regulated, manned, owned and operated (Stopford, 2009). The process of ship procurement, design and construction may be spread between numerous stakeholders and across multiple continents. Subject-Matter Experts (SME) and Human Factors and Ergonomics (HF&E) professionals input in design development contributes to end-user optimization within a system. This is most effective when utilized early and iteratively throughout the design process of a project (International Organization for Standardization [ISO], 2011).

General arrangement (GA) drawings, developed throughout the conceptual design phase, illustrate the basic division and layout of a ship, including side and cross-sectional views of different compartments, location and arrangement of bulkheads, superstructures and major equipment (van Dokkum, 2011). Watson (1998) suggests that the greatest influence on naval architects in formulating a GA is how to best achieve a ship's defined main purpose and satisfy pre-established deadweight, capacity and speed requirements. Engine department GA drawings typically define space allocations and layout of large, primary equipment which impact structural design, stability and performance, and do not include exhaustive system details such as auxiliary machinery, piping, valve placement or electrical structures.

Crew numbers have been consistently reduced over the past several decades in order for shipping companies to remain competitive (Archer, Lewis & Lockett, 1996; Barnett, Stevenson & Lang, 2005; Grabowski & Hendrick, 1993), while increasing automation is continuously altering crew roles and operational pressures (Gretch, Horberry & Koester, 2008). Engine department operation is predominantly performed from remote control centres, with highly automated functions and unmanned engine rooms (van Dokkum, 2011). Although the hands-on, mechanic-style tasks traditionally required in marine engineering have been reduced, machinery and equipment reliability still require on-site inspection, maintenance and troubleshooting (Bloor, Thomas & Lane, 2000). In order to facilitate the new generation of operational demands and increase personnel task efficiency a ships layout must have convenient physical linkages between key areas and equipment. Implementing a more participatory approach to design by integrating end-users throughout the development process can result in better ship designs and safer, more efficient engine department operations (International Maritime Organization, 1998; ISO, 2011).

2. Scope & Purpose

This paper tested a method aimed to utilize HF&E and SME knowledge in the preliminary stages of ship development. The goal was to better understand how nodal connections, personnel movement and logistics between key ship areas relevant for engine crew correspond to GA drawings and physical design. A practical ship design case study was used to explore what type of information can be extracted from GA drawings, its quality, potential value, and how it may be applied pragmatically within ship design.

3. Methods

The Link Analysis method was selected in order to illustrate and analyse relationships between key nodes in GA drawings. Link Analysis is a task description method which produces a generalized summary of activities performed by end-users, focusing on operator actions rather than work-defined tasks (Hollnagel, 2012). The method was first implemented to enhance manufacturing efficiency in a machinery shop by analysing layout and distances between different areas of interest (Price, 1989). Link Analysis provides visual representation of engine crew tasks and movements throughout a ships structure using GA drawings. This can reveal node connections, relationships and routes between key locations within a physical space. The GA drawings (1:200 scale) of a petroleum product and chemical tanker currently in the conceptual design phase were chosen as a case study (see Table 1). A complete set of two dimensional GA drawings (in digital and paper formats) of the entire structure, including top and cross-sectional perspectives of each deck level were used for the analysis.

Ship Specifications	
Deadweight (metric tons)	8000.0
Overall Length (meters)	130.8
Breadth (meters)	18.0
Design Draft (meters)	7.4
Cargo Capacity (cubic metres)	9500.0

Table 1. *Petroleum Product & Chemical Tanker Ship Specifications (approx.)*

3.1 Analysis Criteria

The investigation focused on two logistical aspects of engine department operation: movement of equipment and personnel (1) within the engine room to/from specified nodal locations (Intra-Engine Room), and (2) movement to/from the ship's main deck and the entrance(s) of the engine department (Inter-Departmental). A list of critical equipment, physical locations and operator scenarios were established from pertinent scientific and engineering literature, and SME input.

To investigate the GA Link Analysis method, one engine room equipment item was chosen as an example to explore in detail: marine purifiers. Also known as separators (henceforth here within referred to as “purifiers”), purifiers are critical for the engine department and overall ship operations. Their purpose is to remove impurities from bunkering and lubricating oils prior to being used in a ship’s engine(s). Purifier operation requires high levels of attention from engine crew, necessitating mobile monitoring and on-site maintenance. Various equipment parts (including large, heavy and fragile objects) require frequent cleaning, repair, replacement, and must be transported between the purifier’s location to differing nodes within the engine room, as well as between the ship’s main deck and shore-side. These factors make it an ideal case study item to assess movement logistics and linkages. The analysis covered eight intra-engine room space and inter-departmental nodal linkages (see Table 2). This included scrutiny of the GA drawings investigating layout, routes, obstacles, relative distances, equipment and manual handling aides between the pre-defined nodes.

Table 2. *Key nodal linkages relevant for purifier operational logistics*

Item		Area		Key Nodal Linkages	
1.0	Purifiers	1.1	Intra-Engine Room	1.1.1	General Storage
				1.1.2	Workshop
				1.1.3	Cleaning Room
				1.1.4	Engine Control Room
				1.1.5	Equipment Transport Hatch(es)
				1.1.6	Personnel Passageways
		1.2	Inter-Departmental (Main Deck ↔ Engine Room)	1.2.1	Equipment Transport Hatch(es)
				1.2.2	Personnel Passageways

4. Results

1.1. Intra-Engine Room Movement Logistics

The engine room is spread over two deck levels. Linkages between the pre-defined nodes in the engine room and throughout the ship were mapped on the GA drawings (see Figure 1). The purifiers are located on the lower level, along with one other node: the cleaning room. The other defined nodes of interest, including general storage, workshop and engine control room are located on the upper level of the engine room. Linkage and route data between differing nodes were highlighted and catalogued, as were obstacles such as doorways, stairs and equipment blocking direct passage.

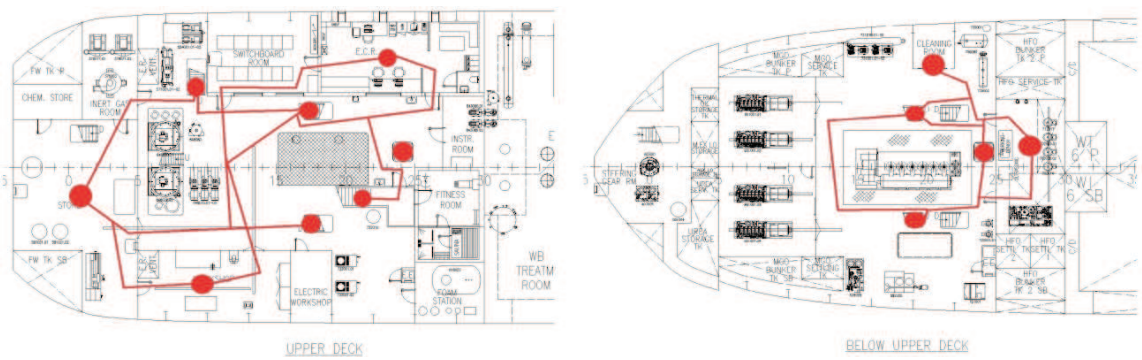

Figure 1. *GA of the aft engine room upper and lower deck nodal linkages*

The analysis revealed a close physical link between the purifiers and cleaning room. This is critically important for crew functions due to the relatively high frequency of maintenance and cleaning required in purifier operation. In theory, this nodal relationship facilitates best practices for purifier maintenance and cleaning due to the close proximity of the proper facilities, personal protective equipment, disposal and ventilation units. Thus, purifier equipment and parts needing cleaning can be conveniently transported between the two nodes. Conversely, a poor linkage, where movement of heavy or awkward parts is inconvenient for crew may encourage on-site cleaning tasks, increasing health and safety hazards and the potential for direct exposure to toxic agents. The GA drawings reveal an overhead crane located directly above the purifiers to facilitate movement and maintenance procedures. However, this is isolated from other manual handling linkages throughout the engine room. There are failed connections of logistical solutions between the purifiers and cleaning room on the same level and even more critically between nodal linkages of the decks above, posing challenges for engine crew.

The workshop, general storage area and engine control room are located on the upper deck of the engine room. Any movement of spare parts or personnel between these areas, as well as the shore-side and main ship deck necessitate inter-deck level movement via cargo hatches or stairways. The GA drawings include the placement of overhead cranes for assistance in manual handling of equipment on the upper and lower levels. However, these are installed predominantly for main and auxiliary engine maintenance and movement. This limited scope, once extended to other equipment reveals poor linkages between other equipment on the same level, and between the upper and lower decks. Heavy, awkward and fragile equipment and stores will inevitably have to be transported between these nodes to the purifiers on the lowest level of the structure. Mobile lifting aides could potentially remedy these logistical problems, but are outside the scope and detail of GA drawings. Ultimately, such solutions fail to resolve the inherent root causes and challenges involving movement of heavy, awkward items.

1.2. Inter-Departmental Movement Logistics

Movement of supplies between the main deck of the ship and upper deck of the engine room spans two levels. The ship is outfitted with a deck crane which allows transport of items to/from the main deck directly into the general storage area of the engine room via a cargo hatch. This provides direct access, not only for purifier equipment, but for any large, awkward or heavy supplies needing to be transported into the upper deck of the engine room. However, it is necessary to consider in detail the specific type of items that will be transported through the areas in question in order for appropriate cranes, hatches and passageways which accommodate expected item loads and sizes.

The superstructure of the ship is located directly above the engine room. Thus, crew accommodation, mess, recreational areas and operational departments, such as the navigation and deck offices are all located in the aft. From the lowest point of the ship (bottom deck of the engine department) to the highest point (navigation deck) the structure spans seven decks. Although the stairs and doorways pose obstacles for movement between the engine department and differing key nodes of the ship, the stacked design and relatively small size of the superstructure creates relatively close linkages.

5. Discussion

Evaluating work environment ergonomic and logistical issues through the analysis of

GA drawings has strengths and weaknesses. Applying the Link Analysis method to a conceptual ship design case study provided a technique which helped integrate human element issues within the traditional process of ship design. The specific example investigating end-user demands in purifier operation revealed nodal linkages between defined areas, revealing several shortcomings in the original GA design. This method illustrated how defining key nodes, highlighting routes and assessing relationships relevant to crew tasks within GA drawings provides insight and feedback for the physical layout.

1.3. Quality of Information Available in General Arrangement Drawings

The Link Analysis method is easy to use, low cost and requires little training to administer (Stanton, Salmon, Walker, Baber & Jenkins, 2005). Most importantly, it can be used iteratively throughout the design and evaluation process as a project develops. However, this method does require SME knowledge of engine department operations in order to motivate the functions and purpose in defining nodes and linkages of interest. A GA drawing gives little information other than defining overall ships spaces, and in the case of the engine department, placement and layout of major equipment and components. Detailed items such as auxiliary equipment, piping, valves, electrical systems, staircase and passageway design, finalized clearance heights or obstructions of machinery parts are not established until later stages of development. This may create false results when evaluating the work environment from GA drawings. In reality, work environments can vastly differ from the general, conceptual design to the finalized detailed work environment. This stresses the need for HF&E and SME input throughout the design lifecycle of a ship.

1.4. Expansion of the Framework

The Link Analysis method can be used as an initial, rudimentary validation tool and point of departure for GA design and work environment analyses. This method establishes a common platform and facilitates a participatory design approach between project stakeholders, promoting integration and evaluation of human element issues in the early stages of ship development. Although GA drawings do not take into account an in-depth analysis of the work environment, organization or socio-technical issues, they can address overview concepts of end-user tasks and equipment nodal linkages. Further expansion to other major equipment and functions would reveal system inter-dependencies. Additionally, this process can be implemented in concert with other HF&E and participatory design and evaluation methodologies to create a richer, more holistic framework.

6. Conclusion

The goal of this investigation was to explore how physical design and layout issues could be pragmatically integrated into marine engineering and naval architecture processes to support design stakeholders. GA drawings and the Link Analysis method provides a platform early in ship design for HF&E and SME knowledge utilization and facilitates an environment where a participatory, inter-disciplinary approach is encouraged. Future work should focus on organizational systems which optimize knowledge management between stakeholders to develop a systematic, domain-specific human element design program.

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