Ocean Engineering 72 (2013) 107–115

Contents lists available at SciVerse ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Generating functional complex-based ship arrangements using network partitioning and community preferences

Justin W. Gillespie*, Anthony S. Daniels, David J. Singer

Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI, USA

ARTICLE INFO

Article history:
Received 18 December 2012
Accepted 11 May 2013
Available online 17 July 2013

Keywords:
General arrangements
Networks
Partitioning
Early-stage design
Facility layout

ABSTRACT

Generating ship arrangements is inherently a problem of identifying the spatial regions to be occupied by shipboard elements while balancing the impact on performance. Traditionally, elements are assigned a Cartesian coordinate location, and the allocation problem is solved in three-dimensional space. The coordinates for each subsequent element are selected by considering the element's interactions with placed and yet-to-be-placed elements. This paper presents a new approach to ship arrangements that starts with a non-spatial, network theory-based perspective and results in the traditional assignment of shipboard items to designated structural zones. Network partitioning is used to identify groups of mutually compatible ship elements, termed *communities*. A metric is introduced to express each community's cumulative preference to be located in specified regions of the ship. The cumulative preferences are used in a direct community-to-structural zone seeding procedure that creates reasonable initial compartment allocations. The rudimentary design knowledge required to position a particular set of shipboard elements using the proposed methods is ideally suited to early-stage design processes.

1. Introduction

Generating ship arrangements is inherently a problem of identifying the spatial regions to be occupied by compartments, systems, and components while balancing the impact on performance. Traditionally, each element is assigned a Cartesian coordinate location, and the allocation problem is solved in three-dimensional space with each coordinate corresponding directly to a position within the final realized ship. The coordinates for each subsequent element are selected by considering the element's interactions (relationships) with elements that have been placed, or are expected to be placed, and in accordance with preferences for residency in specific regions of the ship. This familiar process has been carried over into semi-automated computer-driven systems developed in the past decade.

The concept of developing and analyzing concurrently the relationships between individual compartments, groups of compartments, and the major subdivision of the ship in a non-physical space has not been previously demonstrated. Typically, these considerations are deliberated in the drawing phase, as geometric deck plans emerge compartment by compartment. This paper presents a new approach to generating ship arrangements that starts with a non-spatial, network theory-based perspective and results in the traditional assignment of shipboard items to designated structural zones. A network partitioning method is used to identify groups of mutually compatible ship elements (i.e., compartments, components, and/or systems) that can be located in the same structural zone without degrading other items in the zone. Compartments are placed multiply, rather than singly. The groups can be used as inputs into existing design considerations or as the sole basis for functional zone definitions. If components and systems are included in the network, this approach can also be used to relate equipment to compartments.

The remainder of this paper is organized as follows. Section 2 provides the early-stage ship arrangements context, pertinent network science concepts, and a discussion of related work upon which this paper is built. Section 3 uses a partitioned network example to illustrate a new process for specifying the collective preference of multiple compartments to be located in particular regions of the ship. Section 4 then introduces a process for assigning communities of spaces to structural zones. Then, in Section 5, the number of partitions is varied to observe the effect on the quality of resultant allocations. Finally, Section 6 provides a few concluding thoughts.

2. Background

The ship arrangements problem is largely one of managing relationships among spaces and components. Therefore, design

* Corresponding author. Tel.: +1 734 355 4615.
E-mail address: justinwg@umich.edu (J.W. Gillespie).

0029-8018/$ - see front matter
http://dx.doi.org/10.1016/j.oceaneng.2013.05.007

constraints should be actively managed, rather than simply used as post-layout evaluation mechanisms. Human designers already do this to a certain extent, but the multitude of constraints can be overwhelming. Designers do not randomly place shipboard elements in isolation, but instead continually keep related items in the back of their mind to inform placement decisions. Existing semi-automated approaches for generating early-stage ship arrangements are combinatorial in nature and generate feasible designs through random and "intelligent" configuration adjustments in an evolutionary process driven by objective and constraint functions (Parsons et al., 2008; Daniels et al., 2009; van Oers and Hopman, 2010, 2012). Higher fidelity analyses are now desired in early-stage design; for ship arrangements, this means adding major components and systems to current compartment-level layouts. The resulting exponential growth of the design space makes this increasingly difficult for individuals to manage and optimize.

The early-stage ship arrangement methods described in Andrews and Dicks (1997), van Oers and Hopman (2010) require that the designer define a set of boxes or spatial objects representing the volume to be occupied by a single compartment or system or a set of compartments and systems (see Fig. 1). By aggregating spaces or systems into functional "blocks," the number of objects to be positioned is reduced resulting in a smaller combinatorial search space. Having a good understanding of the contents of each box is important because it influences the properties of the box (size, weight distribution, relationship to other boxes, etc.). Clustering approaches can be useful for estimating the number, type, and size of boxes. Manual (Wagner, 2009; Wagner et al., 2010) and automated (Gillespie et al., 2011) clustering approaches have been demonstrated in the context of ship arrangements. The difficulty of using a manual approach based on domain knowledge and functional breakdowns, as Wagner does, is that multiple layers of constraints may create secondary and tertiary effects that are not immediately discernible, particularly for novel systems or ship types. Gillespie et al.'s network-based approach provides a more comprehensive evaluation of the entire set of relationships.

In contrast to the block layouts described above, the Intelligent Ship Arrangements (ISA) platform (Parsons et al., 2008; Daniels, et al., 2009) is compartment-oriented. ISA situates individual spaces, rather than aggregations of spaces, directly into structural zones with the assistance of designer-inspired intelligent agents. The larger number of elements (individual compartments versus aggregations of compartments) results in a larger design space to be explored.

ISA employs an explicit list of design constraints describing all aspects of the layout. However, the constraints (relationships) among compartments within the problem are used primarily as grading mechanisms, not as the starting point for layouts. These constraints are stored in a constraint database, which dictates design configurations. In ISA, two types of location-based constraints are used. Relative location constraints specify the preference for a compartment to be located in a particular structural zone given the position of another compartment. They fall into two main classes: adjacency and separation. Global location constraints express compartment preferences for being located in particular regions of the ship. The method presented in this paper is capable of generating designs that are as novel or creative as the input global location preferences allow them to be. The method developed provides a robust way to manage the exploding number of unfamiliar relationships that are present when assimilating novel systems into familiar designs, combining uncommon sets of systems, or working within a novel hull form.

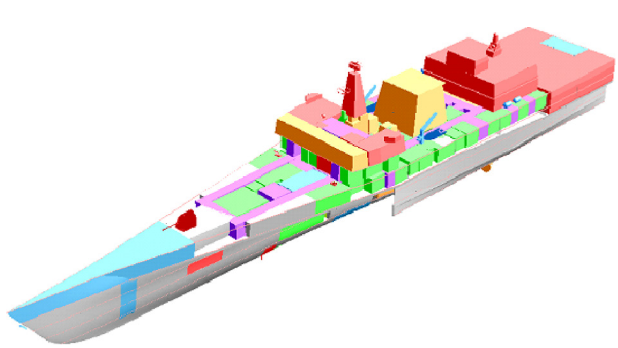

Fig. 1. Example functional block layout (Andrews and Pawling, 2008).

This paper describes a new community-based (or functional complex-based) seeding algorithm for compartment allocations that follows the human thought process more closely than do existing routines. The method exploits the network's ability to comprehensively assess the entire set of layout relationships while providing high-fidelity compartment layouts and extensibility to system and component layouts. The network partitioning approach described in Section 2.2 inherently respects the inter-element relationships, and therefore, its resultant communities form the basis of the subsequent seeding mechanism. It also provides a means for reducing the size of the combinatorial design space, similar to the block layout methods.

2.1. Network science

Network science is the study of the properties of complex networks. Networks are mathematical tools particularly suited to describing interactions or relationships among a set of items. They are commonly used to model social interactions (Newman, 2001; Lewis et al., 2008), ecological and biological relationships (Girvan and Newman, 2002; Xulvi-Brunet and Li, 2010), and many other natural and man-made systems (Cui et al., 2010). Network concepts were used by Laverghetta and Brown (1999) to investigate the ship design process, though not the product itself.

A network is composed of a set of points (called *nodes* or *vertices*) connected by lines (called *edges* or *arcs*) (Newman, 2010). Here, nodes represent ship compartments to be positioned within the ship. Networks may be *undirected* or *directed*; a network is directed if it contains *directed edges*, meaning edges have directionality such that $j \rightarrow i$ denotes an edge from vertex j to vertex i where $i \neq j$. In directed networks, $j \rightarrow i$ is unique from $i \rightarrow j$. Networks may also be *weighted*, in which case edges are labeled with values representing the strength, importance, or capacity of the connection. A *signed network* is one whose edges are designated as *positive* or *negative*. Signed networks are commonly used in the social sciences to denote friendly or antagonistic interpersonal relationships. In this paper, signed relationships signify relative location preferences for being adjacent to (positive) or separated from (negative) another compartment.

Graph partitioning is a process for separating network nodes into groups of a predetermined number (or size) in an attempt to minimize the number of or total weight of edges lying between groups (Fortunato, 2010). Partitioning methods are appropriate for allocating compartments to ship structural zones because the number of structural zones is fixed for a given structural configuration of a hull. A network partitioning approach also is useful for preliminary ship design because it requires only basic, fundamental data about the spaces and components of interest. A designer must supply:

- A list of items to be included in the design (spaces, components, etc.),
- A set of design relationships describing the strength of an adjacency or a separation relationship between two items,