Visualization and Simulation Tool for Automated Stowage Plan Generation System

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Abstract—**This paper presents a tool for the visualization and simulation of automated stowage plan generation for large containership. The stowage plan is generated automatically based on a heuristic algorithm. The allocation algorithm generates different stowage plan in three main stages which includes basic allocation, special container allocation and various stages of stability adjustments. The purpose of this study is to describe how visualization of stowage plan and simulation of allocation sequences can help in the formulation of new and better stowage allocation algorithm.**

Index Terms— animation, stowage plan, simulation, visualization.

I. INTRODUCTION

Stowage plan generation is the process of allocating containers to slot locations onboard containership. The automated generation of stowage plan has recently become a new trend for shipping line to tackle the rapid development of containerization. Currently, stowage planning in most major shipping lines worldwide is still carried out manually by human planners with the assistance of commercial stowage planning software [1]. Most stowage planning software perform three main functions. The first function is to load the stowage plan in standard format, for example, the Electronic Data Exchange (EDI) Bayplan/Stowage Plan Occupied and Empty Locations Message (BAPLIE) format. The second function is to allocate a container or a set of containers to slot based on human planner's experience. Finally, the allocated containers are checked for stability and visibility requirements. For today's large containership which can carry more than 10000 containers, this process is tedious and a human planner can take hours to generate a stowage plan.

In order to deal with the stowage planning for large containership, it is part of this study to develop a fully automated system for stowage planning [1]. The scope of this paper is to extend the existing stowage plan generation module in terms of visualization and simulation as well as manual adjustment to generate the final stowage plan. Figure 1 shows the framework for the automated generation of stowage plan with the visualization, simulation and manual adjustment tool.

Currently, the visualization and simulation tool has been developed and integrated with the stowage plan generation

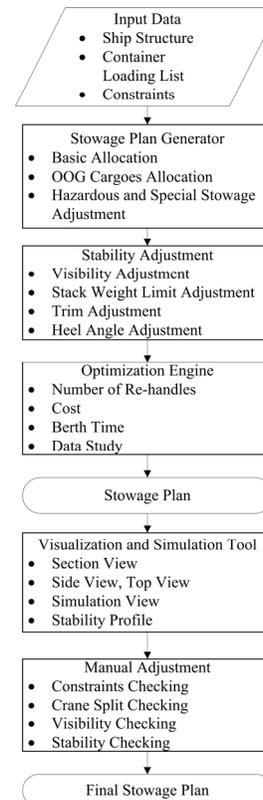module. The manual adjustment tool is still under development stage and will be presented in a future paper.

Figure 1. Framework for Automated Generation of Stowage Plan

A large number of research works has been carried out for the optimization of container terminal in the maritime industry in the recent years. Ilaria Vacca, Michel Bierlaire, and Matteo Salani (2008) made an exhaustive literature reviews on the different optimizations methods that can be applied in the different operations at container terminals [2]. They also explore the status, perspectives of decision problems found in the container terminal and outline the trend of literature for the next future [2]. The main objective of optimization for container terminal is to reduce the ship's turnaround time [2]. Reducing the turnaround time of a containership will also reduce the overall cost of entire voyage. Therefore, optimization of stowage plan onboard containership taking into consideration of multiple ports become key factor to optimize the cost of port usage for shipping line. The research on automation of stowage plan generation has been being carried out by researchers around the world to help in the optimization of intermodal container terminal.

The problems found in stowing containers onboard a ship are named as the Master Bay Plan Problem (MBPP). To optimize the stowage plan it is necessary to solve the MBPP. There are more than one problem during the allocation process of container onboard a ship. Therefore some researcher around the world has been trying to solve one problem or multiple problems commonly found in MBPP using different methods. Ambrosino and Sciomachen (1989) first derive the sets of constraints to solve the MBBP [3]. Aslidis first derives the algorithm focusing on the problems related to stack in 1989 [4]. Aslidis (1990) continues to optimize the overstowed containers onboard the ship. Avriel and Penn (1993) formulate to model the stowage plan in terms of 0-1 binary linear programming [6]. They continue to research on minimizing the number of shifts for loading and unloading operation without considering the weight distribution within a containership for stability feasibility in 1998 [7]. Ambrosino and Sciomachen (1998) continue their research on constraints satisfaction approach to solve the MBPP [8]. Davies, A.P., and E.E. Bischoff consider the weight distribution in container loading operation in 1999 [9]. Wilson, I.D. and Roach, P.A uses the two steps algorithm to generate the stowage plan using branch-and-bound algorithm and tabu search algorithm to allocate the normal containers and special containers [10][11][12]. It takes two hours to generate a non-optimized stowage plan for the 688 TEU containership [10][11][12]. Dubrovsky et al. (2002) [10] applied a genetic algorithm to generate the stowage plan with minimum number of shifts in 2002 [13]. The problems in stowing a containership are modeled in 2004 by Ambrosino and Sciomachen (2004) [14]. They applied the three phases algorithm which partition the ship to allocate a group of containers, assignment of location to each container, and adjustment stage using heuristic algorithm (2006) [15]. They also proposed to consider the ship stability of stowage plan (2006) [15]. In 2007, Sciomachen and Tanfani use a three dimensional bin packing problem to solve the MBPP and present a heuristic solution method to minimize the total loading time and maximize the crane utilization [16][2]. Recent research was done by Delgado and Jensen who apply the constraints programming to solve the allocation of containers into a single under deck bay of a ship [17]. Block stowage is proposed by Xiao et. al. in 2009 to solve the MBBP [1].

Simulation can help in analyzing the operation of container terminal system. Luca Maria Gambardella and Andrea E. Rizzoli [18] review the role of simulation and optimisation in intermodal container terminals. They proposed that well-designed simulation tool will help the decision maker to validate the computer generated policies due to the fact that the decision makers find it difficult to understand the details algorithm behind the computer generated policies. Therefore, simulation tool is to help in evaluation of computer generated policies. In addition to that, the customer demand and container traffic also encourage the container terminal to optimize their performance and use the software tool for port management [18]. Choi and Yun mention that a simulation tool should be designed to provide the user-friendly environments with various statistical outputs [19]. The animation functions in a simulation tool will assist a user in the verification and validation process [19]. The design of simulation tool should also be based on an object-oriented approach to provide reusability and extensibility [19]. Francisco Esquembre introduces Easy Java Simulations, a

tool that is written in Java Programming Language and used to create scientific simulations in Java [20]. Creating a graphical user interface(GUI) for simulation is a tedious job for scientists who are not familiar with the computer programming language. EJS tool helps scientists reduce the time required to create GUI for simulation. Therefore, the researchers can spend more time on fine tuning of their algorithm to be used in simulation. Using a Java programming language also allows the researchers to present their simulation results on several software platforms as well. In addition to that, the result of simulation can be distributed to web using applet easily [20].

In this paper, the development of a visualization and simulation tool for an automated stowage plan generation system will be explained. The visualization tool provides different options to display the stowage plan. The stowage plan can be visualized in accordance with the type of container, size of container, weight of container as well as the loading or unloading port of container. The simulation tool can help in analyzing the allocation algorithm. It will also provide graphical representation of the allocation sequence with flexible navigation system. In order to develop the simulation tool for the allocations of containers onboard the ship, it is necessary to input the slot locations of a ship to present the ship structure. Therefore, the main tasks of current study are to draw the ship structure, visualize the stowage plan and simulate the allocation sequences of each container in the various stages generated by the stowage plan generator.

Section 2 shows the detailed background of the automatic stowage plan generation and how the visualization and simulation tool are integrated with the automatic stowage plan generator. Section 3 explores existing software that can visualize the stowage plan, and allow the manual adjustment integrated with automatic stability and strength checking. Section 4 investigates the slot information of a ship. Section 5 explains the various views for the visualization of stowage plan. Section 6 describes how the simulations of allocation sequence are visualized. Section 7 discusses the features of current visualization and simulation tool. Section 8 explores the possibilities of future enhancement and Section 9 concludes the paper and explains how this tool can be used as a decision support tool for debugging the allocation algorithm in the future.

II. BACKGROUND

There are three kinds of input required to generate the automatic stowage plan. The first input is a ship profile which includes the slots structure of ship and adjustable parameters to be used in the automatic stowage plan generation. The second input consists of container list for the loading and unloading operation at each port on a voyage. The final input includes a list of constraints defined with the help of an experienced human planner.

The automatic stowage plan generator allocates the containers based on a list of heuristic strategies and a set of predefined constraints to generate a feasible stowage plan. Based on these predefined set of constraints, the algorithm allocates the containers and adjusts the containers in terms of special cargo requirements, visibility requirement and stability requirements.

The automation of stowage plan generation consists of various stages including the pre-allocation stage, basic allocation stage, special cargo allocation stage, visibility adjustment stage, and stability adjustment stage (Figure 1). In each stage, the constraints are predefined according to the requirement of shipping company with the help of an experienced human planner. The stowage plan generator generates the stowage plans in the different stages that satisfy the predefined constraints for each stage.

The stowage plans generated in each stage by the stowage plan generator are saved with the detailed allocation history of each container. The visualization and simulation tool loads the generated stowage plan together with the history of allocation sequences. It then visualizes the stowage plan and animates the allocation sequence using the history of allocation sequences (if available).

Figure 2 shows the framework for the integration of the automatic stowage plan generator with the visualization and simulation tool and manual adjustment tool. The visualization and simulation tool is developed in Java. The graphical user interface is designed based on the object-oriented approach. It is developed using the Swing components and Java2D. The GUI component loads the ship profile and opens the stowage plan attached with the allocation details generated by the automatic stowage plan generator. It then stores the history of allocation in the memory. The visualization tool uses the ship profile to draw the structure of a ship. The simulation tool loads the allocation history and animates the allocation sequences.
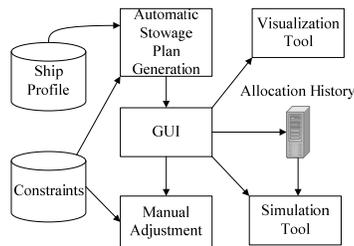

Figure 2. Framework for Visualization and Simulation Tool

It is also necessary to provide for the manual adjustment of the allocated containers generated by the automatic stowage plan generator if the automated results are not feasible due to the stability requirements. The manual adjustment stage allows the planner to adjust each container or group of containers within the predefined constraints. The addition of the manual adjustment tool will be presented in a future paper.

III. RELATED WORK

The visualization of containership can mostly be seen in the field of on-board loading computer systems. There are various kinds of software for the visualization of containership in the market today. Most software can visualize stowage plan and calculate different stability indicators of a ship. Some software can be used in the design of hull structure of ship. Other provides the simulation of loading sequence as well as crane operation.

The trend of on-board loading computer has also been changed by integrating with the various functionalities in addition to the traditional strength and intact stability calculations. Nowadays, loading computers onboard a ship provides comprehensive features according to type of ship. For tank ship, special feature includes direct damage stability calculations. For containership, it is necessary to provide the integrated analysis of a stowage plan in terms of stability, visibility, safety and cost. For bulk carriers, it is necessary to comply with the latest International Association of Classification Societies (IACS) requirements and grain stability features. For passenger ship, on-board casualty response should be provided in the modern software. The exchange of ballast water should also comply with the mandatory international, national and regional ballast water management regulations [21].

The features of loading computer system developed by individual company will be different according to the requirements of individual shipping line company. However, most software fulfils the basic needs for the analysis of containership in terms of visualization of stowage plan, manual adjustment of containers onboard the containership, stability calculation which includes trim, longitudinal strength and stress, intact and damage stability, crane split analysis, and visibility requirements. Some software even monitors the allocation of dangerous cargo and provides the simulation of tank condition as well as online updates of tank information. Table 1 lists some available software with corresponding company and website together with the common features for the loading computer system. The data

Table 1. Comparison Matrix of Common Features in Commercial Loading Computer System and Current Tool

Software Name	Company	Automated Stowage Planning	Multi-Port Vessel Stowage Planning	Simulation of Loading/Unloading	Manual Loading Adjustment	Stability Calculation	Hazardous Cargo Analysis	Crane Usage Analysis	Visibility Analysis	Lashing Analysis	Tank Monitoring
Our Current Work	Research Project with MPA,NTU,APL	✔	✔	✔		✔	✔	✔	✔		
PowerStow Container Stowage System	Navis http://navis.com		✔		✔	✔	✔	✔	✔	✔	✔
LOADMASTER X5	Kockum Sonics http://www.kockumsonics.com			✔	✔	✔	✔	✔	✔	✔	✔
Capstan3	MULLER+BLANCK http://www.capstan3.com		✔		✔	✔				✔	✔
CargoMax	Hertbert Software Solutions http://www.herbertsoftware.com	✔			✔	✔			✔	✔	✔
NEREIDA Loading Computer	S.A. Sedni http://www.sedni.com				✔	✔			✔		✔

shown in the table is summarized according to the common features available from the individual website. The detailed features of the individual software can be obtained from the respective company's website. From the table, it can be concluded that while most existing software help in the stowage planning process with integrated stability checking features, the human planner has to first generate a plan before manually checking the ship stability using the software. These software does not allow the auto generation of stowage plan with integrated stability adjustment as well as visibility adjustment features. Except for LoadMaster, the other software listed do not provides the feature of simulation of loading and unloading operation.

IV. SLOT STRUCTURE OF A CONTAINERSHIP

The locations for the containers to be stored onboard a containership are virtually subdivided into slots. The location of each slot for a container is defined in terms of bay number, row number and tier number. The location is stored in a six digits number. The first two digits represent the bay number, the middle two digits represent the row number and the last two digits represent the tier number. The bay number can be classified into odd bay and even bay which are defined by the combination of two odd bays. The row numbers are classified based on the sea side and port side. The rows close to the sea side are defined with even number and the rows near to the port side are defined with odd number. The smallest row number starts from the middle and gradually increases with an interval of two to the sea side and port side. The tier numbers are the vertical measurement for the slot's location to classify the location on deck and below deck. For example,

the location, 020102 shows that the slot is located in bay number two, row number one and tier number two. Most ship structures use the tier number to define the slot on deck starting from 80 and it is gradually increased with an interval of two. The slots below deck are defined with the tier number starting from tier number 2 and increasing with an interval of two. Figure 3 shows the definition of slot location based on the side view of the containership where bay definition and tier numbering system can be seen and top view where the numbering system for row for each bay can be seen.
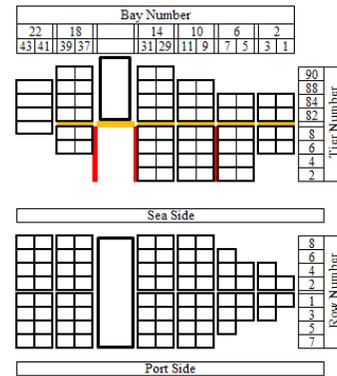

Figure 3. Structure of Slot based on Side View and Top View for a Standard Containership

V. VISUALIZATION TOOL

Two classes of ships are used for testing the visualization of the stowage plan. Figure 4 shows the visualization of a stowage plan for a 5000TEU (twenty feet equivalent unit)
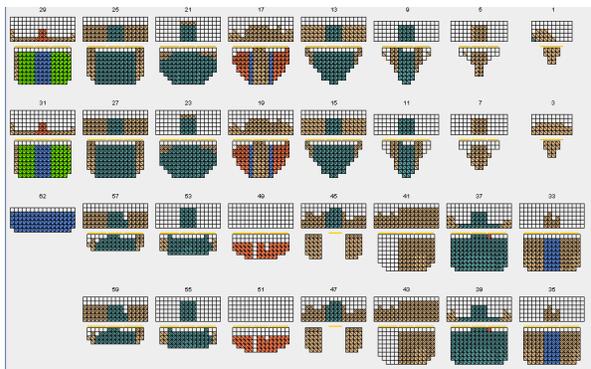

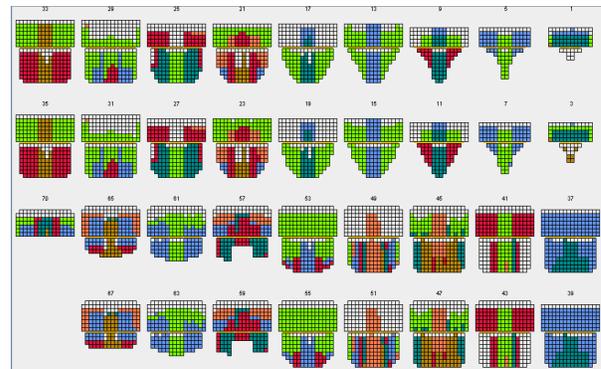Figure 4. Stowage Plan for a 5000TEU Containership

Figure 5. Stowage Plan for a 7000TEU Containership
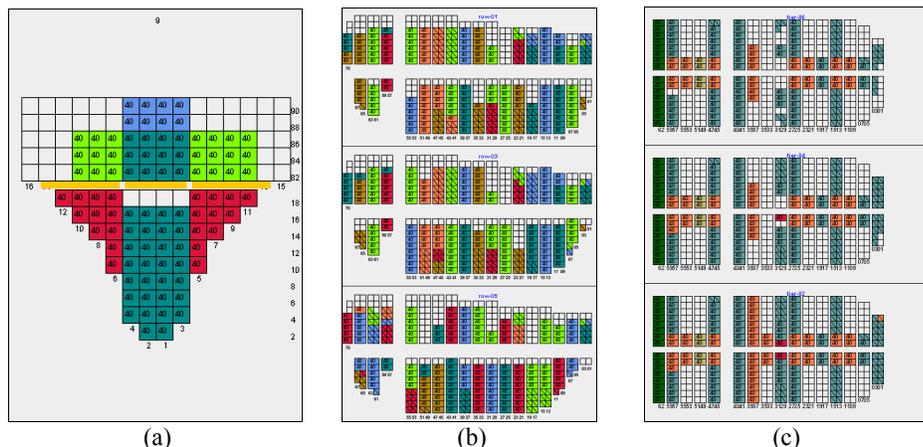

(a)   (b)   (c)

Figure 6. Visualization of Stowage Plan in (a) Section View, (b) Side View and (c) Top View
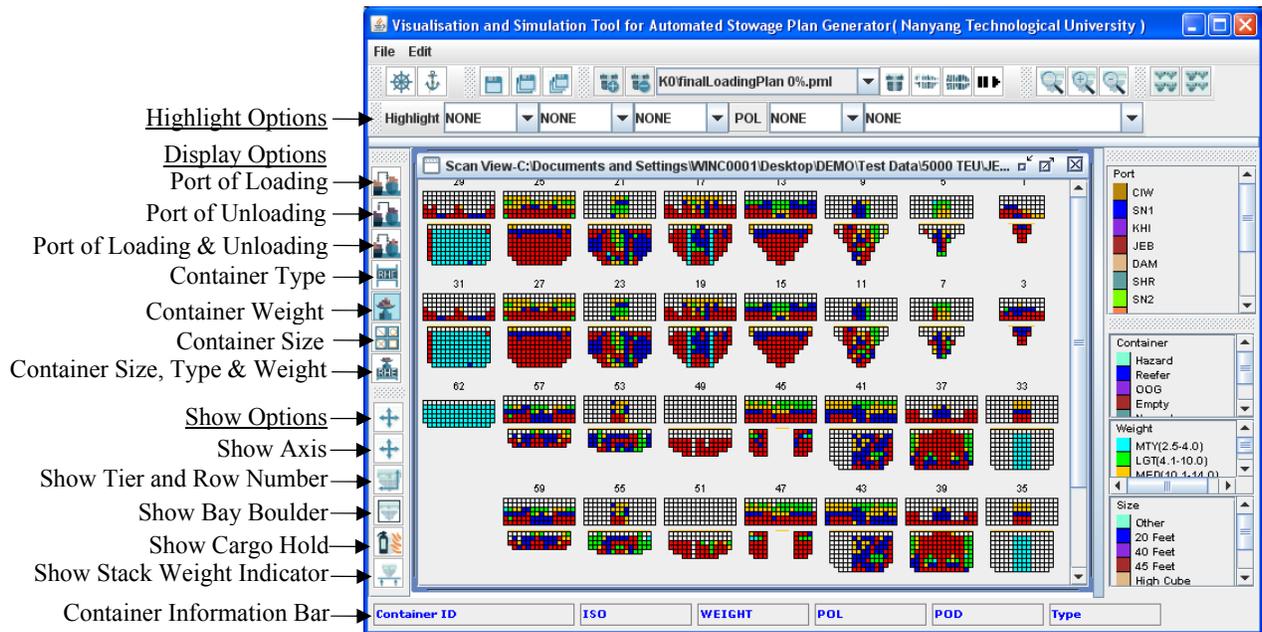
Figure 7. Representation of Display Options and Highlight Options for Different Visualization of Stowage Plan

containership. Figure 5 shows the visualization of a stowage plan for a 7000TEU containership.

The visualization of stowage plan can be viewed in three different ways. Figure 6 shows the visualization of the stowage plan for a containership in the form of section view which displays the slot locations bay by bay, side view which displays the slot locations row by row, and top view which displays the slot locations tier by tier .

The user can also query the information of each container onboard the ship by moving the mouse onto each slot and the details information of each container will be shown in the status bar of the window. The legends of color code in the visualization system are shown at the right side of window so that the user can analyze a certain container type according to color definition. The color code can be edited easily using the color editor provided.

There are different visualization options for the analysis of containership stowage plan. The user can visualize the stowage plan according to the loading port, unloading port, container weight, container size, and container type. For a clearer visual representation for specific sets of containers, group of containers can be highlighted based on container type, container size, container weight, port of loading, port of unloading and constraints. Figure 7 shows the graphical user interface for the current tool that can visualize the stowage plan according to the selected display container highlight options.

VI. SIMULATION TOOL

The simulation of the allocation sequences will help the decision maker to verify and validate the allocation algorithm embedded in the automated stowage plan. In each stage, the simulation tool will allow the user to verify the generated stowage plan to check if the generated stowage plan obeys the constraints set for the current stage. The simulation tool loads the allocation history, animates the allocation sequence and updates the ship model during the simulation process. The simulation tool is used to visualize and animate the

allocation sequences of each container in the various stages. It is to analyze and validate the generated stowage plan in the different stages to check if the generated stowage plan obeys the specified constraints.

In some cases, specific containers will violate the pre-defined constraint due to conditions such as the lack of empty slots and special cargo requirements. In this situation, identifying the individual container which violates the constraints is a tedious job. Simulation tool can help to trace the allocation sequence of that container with the help of animation and interactive simulation for the formulation of a better allocation algorithm. Therefore, the design and implementation of a visualization and simulation tool to visualize the stowage plan and animate the simulation results generated by the automated stowage plan generator become a part of the project (Figure 1).

The input requirements for the simulation engine is the ship profile where the location of slots for a ship is stored, a stowage plan which stores the list of containers with their selected locations, and the allocation sequences generated by the stowage plan generator. The allocation sequence is divided into different stages. Each stage has its own heuristic algorithm to allocate a container into a slot. Generally, each allocation sequence in the different stages performs one of four operations which include loading a container into a slot, moving a container onboard a ship into an empty slot, unloading a container from a slot, and exchanging container A in location L1 with container B in location L2. Figure 8
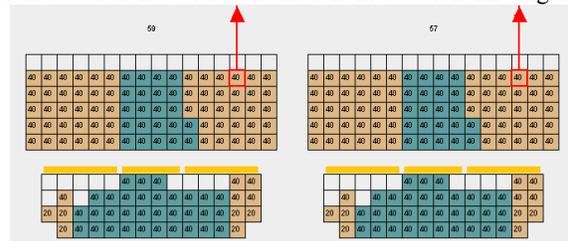

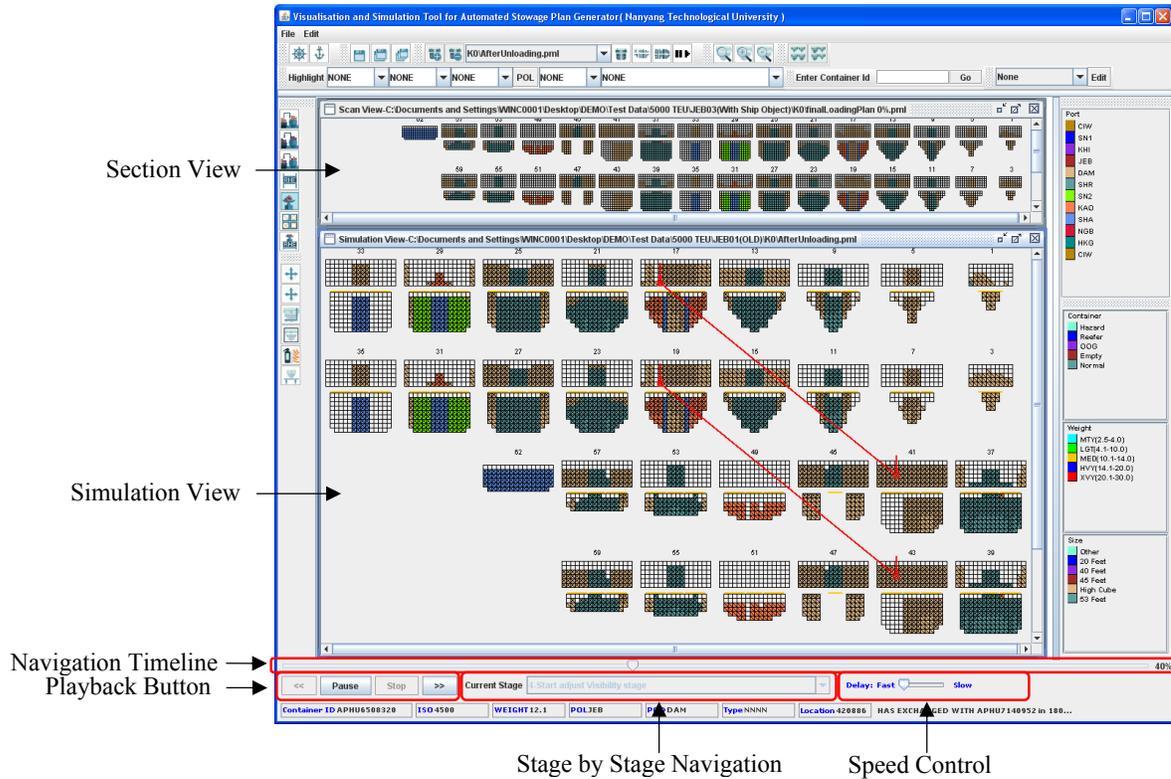Figure 8. Unloading of Forty Feet Container

Figure 11. Layout for comparing final loading plan and simulation results

shows the graphical representation of the unloading of forty feet container from an even bay. Figure 9 depicts the operation that swaps two containers where a red line is drawn between two containers which are exchanged for a clear
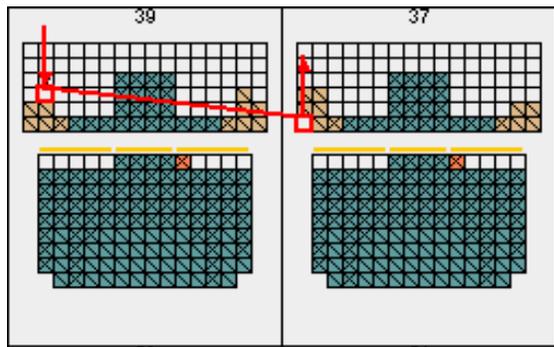

Figure 9. Exchanging Twenty Feet Containers

visual representation. The simulation of the moving of a container into an empty slot is represented as a combination of a loading and an unloading operation.

The simulation engine is designed to perform the four operations mentioned above with the different navigation systems to animate the allocation sequences. The user can animate the allocation sequence in three navigation methods as shown in Figure 10. The first method is to let the simulation engine play automatically allowing the user to pause, stop, and adjust the playback speed. The second method allows the user to playback the stowage allocation sequence using the timeline or play back button. The third
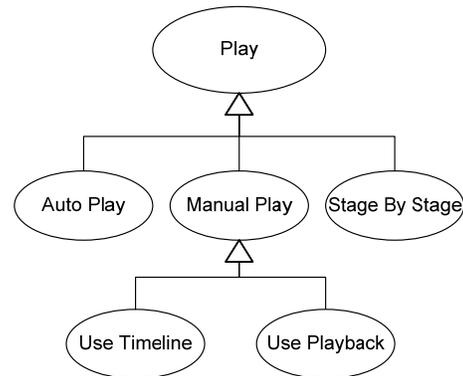

Figure 10. Navigation Options in Simulation System

method is to move to a specific stowage allocation stage directly.

Figure 11 shows a screenshot of the simulation view of the visualization system. The main function for the simulation is to show the change of location for each container during the stowage allocation process. During the simulation, the users are allowed to change the display options. The visualization system also allows the highlight feature during the simulation process. The user can also disable containers that are loaded from the previous port so that the user can focus on the containers that are being loaded in the simulation according to the current port he/she selected and type of port.

VII. DISCUSSION

The current visualization tool provides various display options in term of port of loading, port of discharge, type of

container, weight of container and size of container. It provides the different highlight features to highlight a container or group of containers according to the specific type of container, weight of container, size of container. It also provides to highlight a container or group of containers based on the selected port of loading and port of discharge. The ease to use zoom feature also allows the user to analyze containers at different locations of the ship. The zoom feature also applies the level of details algorithm which shows specific information at the specific zoom level.

The visualization tool also allows the user to show or hide the information of each bay including labeling of each bay, stack weight information, cargo hold separation as well as border of each bay. The simulation tool provides different navigation methods to give the user more degree of freedom for the analysis of the allocation algorithm during the simulation.

In addition to that, the generated stowage plans can be visualized and compared by loading multiple plans in the same window. It allows the planner to compare different stowage plans generated with different parameter settings. The detailed results of the current visualization tool and simulation tool can be seen in Figure 7 which explores the features of visualization tool and Figure 11 which shows different navigation methods for simulation as well as multiple windows management feature.

VIII. FUTURE WORKS

The current visualization and simulation tool will be further improved. One immediate improvement is to provide manual adjustment with integrated constraints checking facility so that containers which violate constraints can be manually adjusted by human planner.

IX. CONCLUSION

In this paper, we have described our current modeling and simulation tool. The current modeling and simulation tool provides different visualization options, highlight features, and navigation methods. It can also be used for analyzing the allocation sequence of the automated stowage plan generator. Examining the allocation sequence of containers can help in the derivation of better algorithms to generate stowage plan that maximizes the stability as well as minimizes the time a ship spend at port. A plan with good stability is a key factor to consider for a ship to have a safe trip. At the same time, a plan that achieves the minimum port stay also reduces operation cost for the shipping company.

With the addition of stability profiling feature, the user can easily investigate the sequence of container allocations and formulate alternative algorithms to maximize ship stability. Our future work will integrate the simulation tool with the stability profiling module, the tank information module and visibility profiling module to derive better algorithm to allocate containers for the optimization of stowage plan.

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