Supporting Ship Overhaul with Customized Discrete Event Simulation

Karina Lilliston
Newport News Shipbuilding
Newport News, VA
Karina.E.Lilliston@hii-nns.com

W. Russell Shaffer
Newport News Shipbuilding
Newport News, VA
William.Shaffer@hii-nns.com

ABSTRACT

Newport News Shipbuilding is the only shipyard that builds nuclear powered aircraft carriers and is one of only two companies that build nuclear powered submarines for the U.S. Navy. In addition to constructing these, one of the many services that Newport News Shipbuilding provides is the periodic overhaul of existing U.S. Navy aircraft carriers. These aircraft carriers have thousands of compartments that require various work activities at varying extents. This paper presents a simulation project effort aimed at simulating the work activities, predicting work completion milestones for comparison with scheduled milestones, and showing the current status of work during the overhaul process. This problem space and project effort required a specific modeling and simulation approach that differs from most typical discrete event simulation models, primarily because the duration of individual work activities is determined based on the scope of the work, not an assigned length of time. This paper will summarize the problem space, the approach, the resulting tool, and its use cases.

ABOUT THE AUTHORS

Karina Lilliston is a Modeling and Simulation Apprentice at Newport News Shipbuilding. Ms. Lilliston is responsible for fulfilling a designated role based on assigned rotations of analysis, software development, data collection/user support, graphic arts, and project research & development. Prior to joining the Modeling and Simulation Department, Ms. Lilliston served as an Electrician for Newport News Shipbuilding. This allowed her to become acquainted with NNS and their projects. Ms. Lilliston is currently a student and is pursuing an Electrical Engineering Technology Bachelor's Degree from ODU with a Minor in Modeling and Simulation.

William Shaffer (Russ) is a Systems Modeling and Simulation Engineer at Newport News Shipbuilding. Since 2011, he has been serving the roles of Product Owner/Project Lead and Analyst for various simulation models and project efforts including numerous aspects of aircraft carrier overhaul and shop operations. He also instructs the Introduction to Modeling and Simulation classes taught to incoming Modeling and Simulation Apprentices. Prior to Newport News Shipbuilding, he graduated from Virginia Tech in 2008 with a Bachelor's Degree in Industrial and Systems Engineering and later from The College of William and Mary in 2011 with a Master's Degree in Computational Operations Research.

Supporting Ship Overhaul with Customized Discrete Event Simulation

Karina Lilliston
Newport News Shipbuilding
Newport News, VA
Karina.E.Lilliston@hii-nns.com

W. Russell Shaffer
Newport News Shipbuilding
Newport News, VA
William.Shaffer@hii-nns.com

INTRODUCTION

Newport News Shipbuilding is a government contracted shipyard that exclusively builds and overhauls the US Navy's aircraft carriers and is one of only two shipyards that builds US Navy submarines. Since 1998, Newport News Shipbuilding has taken on the US Navy aircraft carrier overhaul process, a process most aircraft carriers go through during their commissioned time period. Since aircraft carriers are comparative in size to a large skyscraper (on its side), it is easy to imagine the immense complexity and volume of the work activities involved. It is a strenuous process that requires the effort of thousands of shipbuilders to reconstruct/refurbish ship spaces and structures, remove/add equipment, and test and modify various ship systems over a period of approximately four years. This requires years of tracking sequential and simultaneous work efforts that (often unknowingly but inevitably) create a multitude of constraints, work conflicts, and daily unforeseen obstacles. Superintendents, construction supervisors, foremen, tradesmen, and planners are some of the people faced with this daunting task.

The Modeling and Simulation department of Newport News Shipbuilding (NNS) has designed a unique discrete event simulation tool that captures the general complex overhaul installation phase workflow (of a particular aspect of the overhaul). Containing what is known as a "simulated foreman," this tool embodies the expertise of various subject matter experts, translates company status, schedule, and budget reports, and uses comparative work scope logic to drive establish the model representation of the current status and remaining work and then simulate it through time. The information presented in this tool helps the shipbuilders mentioned above throughout the overhaul evolution to predict the status of relevant milestones and provides situational awareness of current or potential setbacks to work status. Ultimately, this tool (internally known as the Compartment Completion Simulation Model) provides an effective set of analytical tools to support various roles involved in the planning and execution of an aircraft carrier overhaul.

PROBLEM SPACE

Complex Overhaul: Compartment Completion

As mentioned above, the aircraft carrier overhaul is a vastly complex process that performs maintenance and/or enhancements on countless structures and functional systems throughout the aircraft carrier. Specific to the problem space of this paper and simulation tool to be described later, there are approximately 2,500 compartments (rooms within the decks of the ship) that may require work within them during the overhaul. The process of performing this overhaul work in the compartments is often called 'compartment completion.' Something notable about this particular aspect of the aircraft carrier overhaul is that the cumulative scope of work activities that are required in a compartment are highly variable among all compartments. For example, even two compartments of relatively similar size and purpose could have two very different sets of required work activities and/or corresponding estimated work durations in order to be said complete. In addition to the variance in the required work within a compartment, these varying activities need to be coordinated in order to prevent damage to/reversal of previous work and/or to follow preferences established by those involved in executing or tracking the status of work. This coordination is required both within a single and among many compartments at any given time throughout the compartment completion effort.

Given the large number of possible work locations and the highly variable work process to complete compartments, it is often difficult to visualize all layers of work statuses while the carrier overhaul process is in progress. There is little ability to see the downstream effects of the many potential delays, which oftentimes only results in the ability to plan/adjust schedules reactively. The current tracking methods and tools are limited in their ability to predict problems or situations beyond what is written in the schedule. Additionally, how the work is categorized to be planned, scheduled, and executed differs from how work progress is categorized to be tracked and presented as complete to the end customer (The Navy). These collective limitations make it difficult for one to proactively plan for potential setbacks (rather than only react once a setback has been realized). A more detailed understanding of the layers and relationships of the complex overhaul system workflow is vital to effectively track and help predict job progress.

Current Tracking Tools

Before an aircraft carrier arrives at the shipyard, there is a planning period where the work that is determined to accomplish the overhaul is planned and scheduled. This is achieved by dividing the work into 'work packages' (or 'package'). Each work package contains information such as: description(s) of the work task(s), trades involved, scheduled and actual start and finish dates (also called open and close dates), and budget allotted (in man-hours). Throughout the execution of the overhaul, the work progress made towards these packages is tracked (e.g. actual start/finish dates, man-hours spent towards the package, estimated percentage of progress, etc).

The completion of the work with respect to compartment completion, however, is categorized and tracked from a different perspective during the overhaul. When all of the work within a compartment is complete and the compartment is its final condition, it is presented to the Navy for inspection and turnover. Further, there are scheduled milestones and key events throughout the overhaul, to which groups of compartments (generally because of their contributing function to the ship) are assigned; a milestone or key event is met when all of the compartments assigned to it have been presented.

Unfortunately, the relationship between work packages and compartments is not a simple one-to-one; a compartment could have 0 to many work packages and a work package could contain work in 1 to many compartments. Since the work being performed is tracked at the work package level, it is often difficult to have visibility into the progress in one specific compartment. To those coordinating higher level portions of the overall compartment completion effort, this type of visibility is a necessity to track progress towards the milestones and key events mentioned above. Additionally, the static scheduling tools currently in use only offer insight at the package level and not necessarily how the work in a compartment will actually be performed (with respect to work sequence and constraints). With this in consideration, the need for a method to help translate the work scope and progress from the work package(s) to the compartments and a way to see future projections at this level quickly became evident.

COMPARTMENT COMPLETION SIMULATION MODEL

Description of Simulation Model/Tool

The Compartment Completion Simulation Model is a discrete event tool that has been uniquely designed to support one of the largest aspects of a ship's overhaul process. The simulation model depicts the past, present, and projected future states of specified compartments and their steps/jobs, milestones, and key events. For any given simulation replication, the tool first partitions and translates all available work definition and progress data from work packages to their respective compartment-level categorization; from there, the tool takes note of any past progress based on the various status reports, establishes the current progress based these reports, and then produces likely future outcomes by simulating the remaining work. A combination of actual and/or simulated work events/steps, with an established overhaul process flow, are maneuvered by process priorities and constraints. This is how the model logic/Simulated Foreman predicts what will transpire from the established present state forward (or all the way through if performing a full simulation of all work).

In addition to what goes on within the tool's operation, the simulation model provides a visualization of the work status as initialized by work progress data and/or throughout time in the simulation. The visualization includes an overall compartment layout within the decks and a compartment process flowchart that adjusts based on the specific compartment selected; together, these provide a visual summarization of work status at the ship and a compartment's level. Because the visual features effectively display the numerous and various statuses in an encapsulated and manageable format, those in various roles like planners, supervisors, and others contributing to the work can utilize this tool to their advantage in tracking their areas of responsibility.

Compartment Flowcharts and Work Breakdown

With subject matter expert (SME) knowledge and input, a general inclusive workflow of the carrier overhaul process across all compartments was established within a flowchart structure (see Figure 1 below); this flowchart represents the broad steps that any compartment *could potentially* have to perform during compartment overhaul and gives a visual generalization and status at the compartment level. To differentiate and organize work packages into their relevant steps on the flowchart, each work package is assigned a code. These codes categorize the work package based on the nature of the work it contains; some examples of the categorization criteria are: its main trade and keywords from the work package title. Each work package-to-step relationship within a compartment is called a 'job' in the model; this layer is necessary since multiple work packages could possibly perform the same type of work in the same compartment (and/or a work package could span across multiple compartments). Because each flowchart contains all of the possible steps of any one simulated compartment found in the compartment overhaul process, each step does not apply to each compartment. Steps in compartments that do not have any related work packages are simply highlighted gray and read "Non-Applicable" in its customized flowchart.

At the beginning and during a simulation replication, the steps of the flowchart are synchronized with the appropriate jobs and display a collective status for each step. Each step's status, presented as a colored border whenever some progress has been made for that step, represents the worst case scenario of all jobs within the step. These statuses/colors include: early/on schedule (green), late (yellow), or exceedingly late (red) and are determined by a collection of actual or simulated jobs (or both).

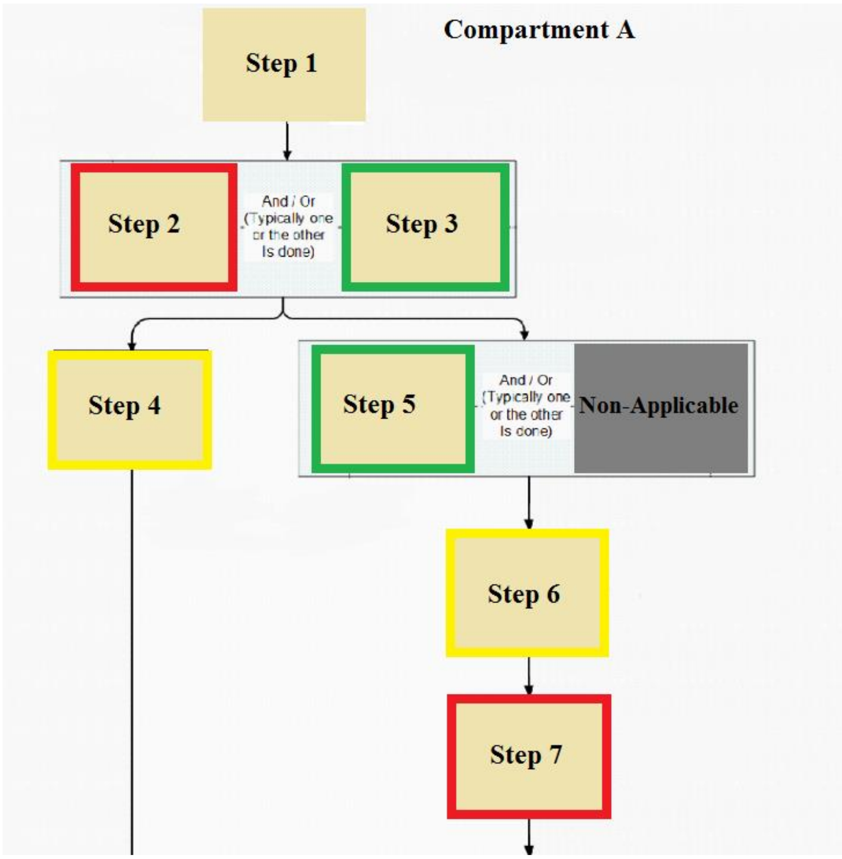

Figure 1 - Example of a Specific Compartment's Flowchart

As mentioned before, work packages can perform the same type of work in multiple compartments. To accommodate this and partition the work effort into the individual compartments, the model uses the square footage of each simulated and non-simulated related compartments that share jobs within a work package. A ratio is derived to establish the distribution of a work package's budget to the jobs within it. Known as the "compartment square footage ratio," this allows the model to allocate the correct percentage of a work package's assigned budget (in man-hours) based on a relative comparison of the size of a compartment as compared to the others (using the square footages of all compartments linked to each work package). The portions of budget dispersed to an individual compartment represent the relative effort it takes for the simulation to consider the job complete during the simulation. The group codes and compartment square footage ratio are how the work package tracking method is translated to the compartment level tracking method.

Simulated Foreman:

Simulation, Constraints, and Priorities

To simulate the jobs/steps in the model, the progress of jobs is guided using hard and soft constraints and priorities daily. Initially set up in the model's input file, these factors govern the logical order that compartment steps and jobs take place. A compartment's flowchart displays each possible step in a sequenced or simultaneous order. Constraints dictate when a step can take place; a constraining relationship can be applied to the start, end, or at a partial percentage complete of a previous or parallel step. Priorities are used to decide which job or compartment is more significant over another. For instance, a compartment with an earlier key event date takes priority over another compartment that has more time to reach its key event date.

Beyond constraints on step flow, limitation factors that manage the daily distribution of budget are also put into place. The budget (number of man-hours) dispersed to jobs daily is equally representative of the progress made towards jobs in the simulation model. Because of this, regulating the amount of budget available each day and the amount dispersed to a job or compartment is a way of simultaneously advancing the progress of simulated work as well as imposing representative personnel restrictions. These restrictions are applied in two different ways. First, the daily amount of budget dispersed is limited to an equivalent number of man-hours derived from all work package's budgets scheduled during that time, which represents only having a certain amount of personnel available each day. Second, a limitation factor called "daily compartment cap" confines the number of man-hours spent in a compartment by only allowing a specified amount of budget to be spent per square foot of each compartment daily, which represents space constraints with respect to the number of people performing work in a compartment. Each day in the simulation, every eligible job (based on step constraints) will request its compartment cap of man-hours. Since budget and progress are assumed equal, any overflow of unspent daily budget (e.g. a step was constrained and unable to spend its scheduled budget) will be redistributed within the available man-hours for working days in remainder of the month. This method of simulation differs from typical discrete event simulation; it is based on a fixed simulation time increment where events are evaluated and initiated based on the rules and constraints of the Simulated Foreman. The simulated duration of a job is the number of days between first receiving budget from the Simulated Foreman and the day it received that last amount of budget to complete its assigned man-hours total rather than a realization from an assigned duration distribution.

Initialization of Actual/Current Status

Actual job progress is another important factor that is taken in to account. This is incorporated in the initialization phase of the model where job progress data are translated and used to bring the simulation model to the overhaul work effort's current state. The data used in this initialization process are often referred to as 'actuals' since it is based on actual ship-board progress information, as opposed to simulated progress information. Actual data is obtained and translated from a few sources of NNS status documentation, which provides a combination of work package actual start dates, actual finish dates, completion codes (e.g. complete/In progress), and various job progressing methods that are used. At the initialization of a simulation replication, work packages that have an actual finish date (or are otherwise progressed as complete) will not be simulated.

Other work packages that only have an actual start date (and no finish date), have a completion code implying an in-progress status, and/or have a progress percentage anywhere between 1 and 99 percent are referred to as 'partial actuals'. A partial actual is a work package that has actually started progress but has not reached a point of completion (based on the data being used/start date of the simulation). In this case, part of the progress is marked as complete and only the remaining percentage of work (in man-hours) will be simulated.

Once all progress has been determined, the necessary adjustments in the scheduled budget can be realigned and any unused scheduled budget will be reallocated as mentioned above (since budget and progress must be one-to-one).

Transitioning out of the initialization phase, all unspent budget will begin to be distributed among the jobs that have yet to reach completion. Following the guidelines of the simulated foreman, the simulation begins from the status established by the actual and partial actual data and then begins to project the outcome of the remaining jobs, compartments, milestones, and key events. The simulation with run until every job has reached completion, which is determined by a job receiving all of its assigned man-hours from the simulated foreman.

Simulation Output, Reports, and Analytical Tools

Both during and after the completion of a set of simulation runs, model graphics, reports, and output files have proven to be a useful set of analytical tools. Shipbuilders are able to use these tools to their advantage by identifying and defusing conflicts before they transpire. The graphics/visualization displayed during a simulation run provides an intuitive visual summary of the work progress that is normally contained in long digital files and/or many sheets of paper. Similarly, the various reports available in the simulation model summarize data from a set of runs; some examples of the kinds of data summarized are: rate of completion of compartments, spending rate of man-hours, multi-level work progress, and general compartment/work package information.

During a visual simulation run, wireframe layouts of the compartments on the aircraft carrier (by deck) enable the model to display a milestone status that can be observed at a glance. The compartment shapes on the carrier outline turn different colors that represent an actual or simulated status of early, late, or exceedingly late milestone date (see Figure 2 below). By selecting a compartment shape, the user is able to investigate further and observe the compartment's customized flowchart that provides a more detailed visual status of individual steps and jobs (as seen in Figure 1 above).

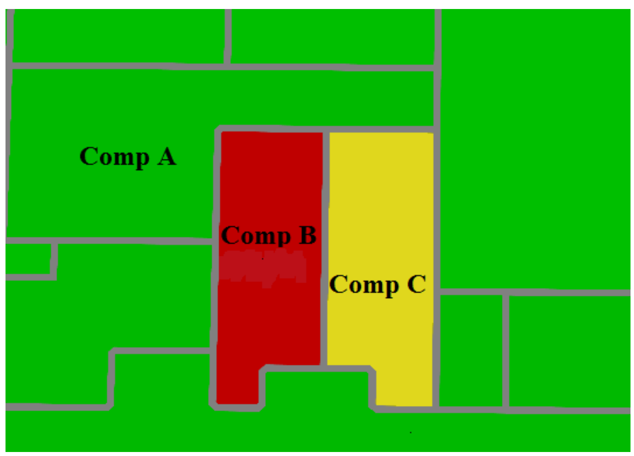

Figure 2 - Arbitrary Compartment Layout

After a set of simulation runs is complete, various reports and charts can be reviewed to investigate various aspects of the projected work forecast. When viewing results in report form, various interactive charts and tables allow the user to pinpoint various areas of concern. Interactive charts, such as the key event drill down chart, allow the user to do exactly that by quickly stepping down into a more detailed portion of the report.

The interactive key event drill down chart displays an overall status of all compartments associated with each key event contained within the model (see Figure 2 on the next page). By selecting a key event, the Key Event Readiness Chart displays when actual/simulated work occurs on a compartment Gantt-style chart and then allows the user to drill down even further to a step level and/or a job level Gantt-style chart when prompted by the previous chart (through a mouse click). With adjustable chart parameters, the user also is able to filter and experiment to make decisions supported by the information presented in the predicted outcomes.

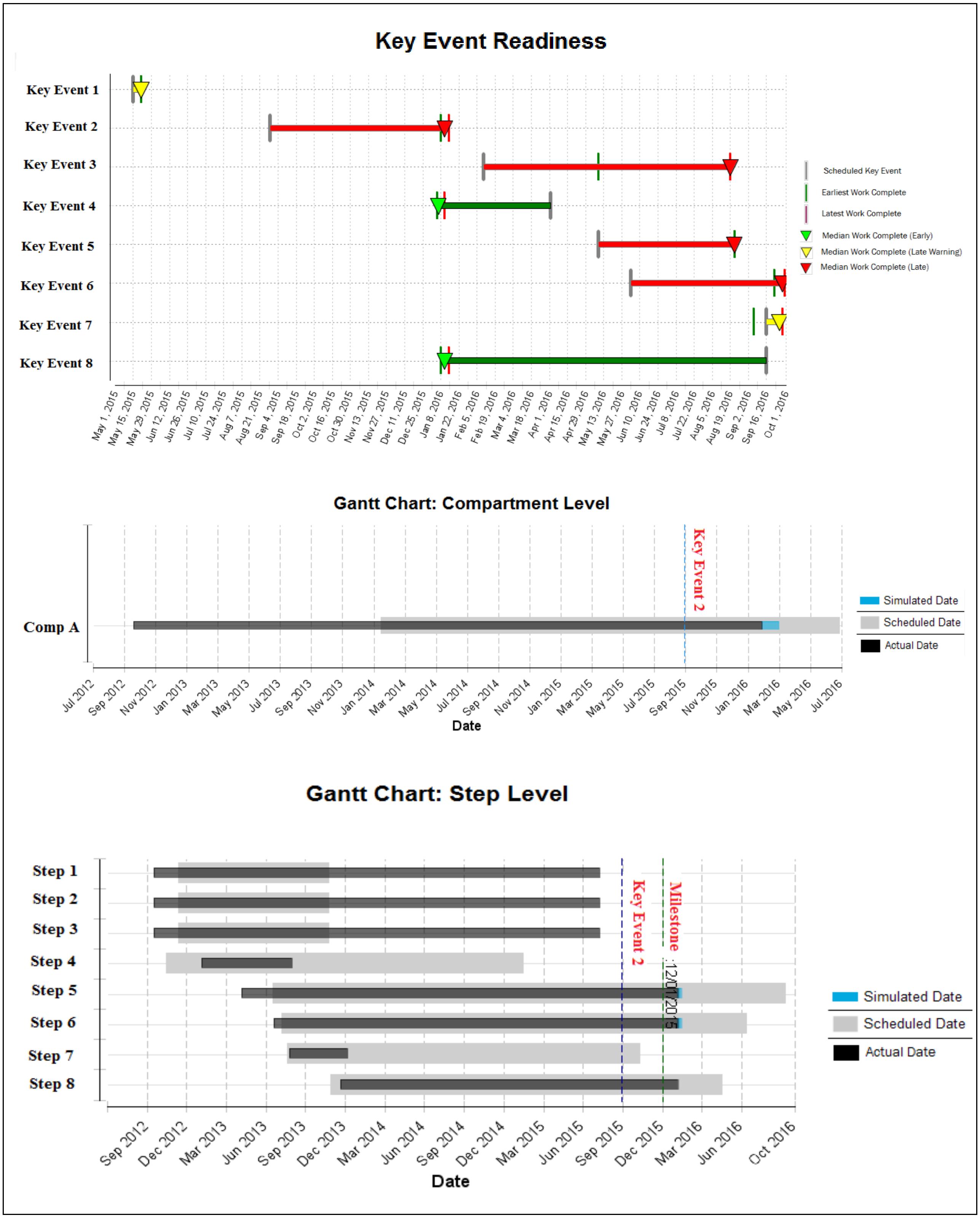

Figure 3 - Key Event Readiness Interactive Chart

The charts above are included in the most frequently used report from the simulation model. The tool contains a number of other charts and reports to provide insight into other aspects of the work projection. For example, there are charts to show the simulated spending rate (in man-hours) for various trades, which provides an expectation of the personnel requirements for the projected work schedule. Other charts show a projected rate of completion with respect to number of compartments completed per week; this can be compared to weekly goals at the shipboard level. Finally, there are reports and simulation output files that can give context to work package and compartment statuses, as well as any discrepancies within them (e.g. a work package is missing budget information and may not be simulated properly)

CONCLUSION

For any one individual, tracking the trajectory of thousands of compartments is perplexing. The variance between these compartments has been expressed in a general flowchart across all compartments that contributes to an overall compartment layout of the simulated compartments. The Compartment Completion Discrete Event Simulation Tool has captured the combined knowledge of shipbuilders and information from various status reports. It allows the user to view the actual and/or predicted status of desired compartments, milestones, or key events with minimal effort. Persons such as construction supervisors are able to pinpoint problem areas and plan ahead to prevent future occurrences of setbacks before they take place. Such a tool also allows for scenario experimentation by adjusting input data and comparing the simulation results (e.g. “What if we …”). By doing so, the user is able to not only address a future problem area but is able to explore potential outcomes. With all of the use cases described in this paper, this tool has become invaluable to overhaul effort, to include weekly use in support of multiple supervisors performing the compartment completion overhaul effort.

ACKNOWLEDGEMENTS

The authors would like to thank the Compartment Completion Project Team and the Modeling and Simulation Department of Newport News Shipbuilding (NNS) for their support and development of this project, specifically: Travis Evans, Thien Nguyen, Kelsey Shkuda, John Vasquez, and Julie Mcketney. They would also like to show appreciation to the Subject Matter Experts that have provided their time and input throughout the duration of the project.