iMAST
Institute for Manufacturing and Sustainment Technologies

IN THIS ISSUE

DIRECTOR'S CORNER

Timothy D. Bair

This past summer was my ten-year anniversary as the director of the Institute for Manufacturing and Sustainment Technologies. I found that hard to believe. So here are some thoughts as I look back with some nostalgia and a little prophetic glimpse into the future….

The ManTech budget has been mostly static for most of my tenure. Unfortunately inflation and the cost of doing business has not been. The number of projects iMAST had in its portfolio ten years ago averaged around 32. Today, our portfolio of active projects includes 16 projects in

Continued on Page 2

Hahn Assumes Helm of Office of Naval Research

Rear Admiral David J. Hahn recently assumed leadership of the Office of Naval Research, becoming the 26th Chief of Naval Research with concurrent flag responsibilities as Director, Innovation Technology Requirements, and Test & Evaluation (N84). Admiral Hahn succeeds Rear Admiral Mathias W. Winter who has assumed duty as deputy director, Joint Strike Fighter Program, Under Secretary of Defense for Acquisition, Technology and Logistics. The admiral arrives at the Office of Naval Research following duty as special assistant to the Deputy Chief of Naval Operations for Information Warfare.

A 1985 honor graduate of the United States Naval Academy, Admiral Hahn earned his Dolphin pin and served aboard the USS Casimir Pulaski (SSBN 633), USS William H. Bates (SSN 680) and USS Springfield (SSN 761), deploying to the North Atlantic and Western Pacific, conducting multiple strategic deterrent patrols. Ashore, Admiral Hahn served as flag lieutenant to Superintendent, U.S. Naval Academy; squadron engineer, Submarine Development Squadron 12; action officer, Joint Staff in the Command, Control, Communications and Computers(C4) Directorate; and legislative fellow on the staff of U.S. Senator John Warner.

US Navy Released Photo

Admiral Hahn commanded the USS Pittsburgh (SSN 720) from September 2003 to January 2007.

Continued on Page 11

PennState Applied Research Laboratory
A U.S. Navy Manufacturing Technology Center of Excellence

iMAST ★★★★★★★
Institute for Manufacturing and Sustainment Technologies

DIRECTOR, iMAST & NAVY/MARINE CORPS REPAIR TECHNOLOGIES
Timothy D. Bair
(814) 863-3880 tdb14@arl.psu.edu

MATERIALS PROCESSING TECHNOLOGIES
Timothy J. Eden, Ph.D.
(814) 865-5880 tje1@arl.psu.edu

LASER PROCESSING TECHNOLOGIES
Richard P. Martukanitz, Ph.D.
(814) 863-7282 rxm44@arl.psu.edu

COMPOSITES MATERIALS TECHNOLOGIES
Kevin L. Koudela, Ph.D.
(814) 863-4351 klk121@arl.psu.edu

MANUFACTURING SYSTEMS TECHNOLOGIES
Mark T. Traband, Ph.D.
(814) 865-3608 mtt1@arl.psu.edu

SYSTEMS OPERATIONS AND AUTOMATION/ COMPLEX SYSTEMS MONITORING
Eddie C. Crow
(814) 863-9887 ecc1@arl.psu.edu

DRIVETRAIN TECHNOLOGIES
Aaron C. Isaacson
(814) 865-5832 aci101@arl.psu.edu

iMAST ADMINISTRATION and EDITOR
Gregory J. Johnson
(814) 865-8207 gjj1@arl.psu.edu

FINANCIAL COORDINATOR
Brenda E. Kephart
(814) 865-3264 bew3@arl.psu.edu

WORLD WIDE WEB
http://www.arl.psu.edu/centers_imast.php

NAVY PROGRAM MANAGER
Gregory D. Woods
gregory.woods1@navy.mil

©2016. The iMAST newsletter is published by the Institute for Manufacturing and Sustainment Technologies of the Applied Research Laboratory at Penn State, University Park, PA. iMAST is sponsored by the U.S. Navy Manufacturing Technology (ManTech) Program, Office of Naval Research, under Navy Contract N00024-12-D-6404. Any opinions, findings, conclusions, or recommendations expressed within are those of the authors and do not necessarily reflect the views of the U.S. Navy. Send mail list requests or address corrections to: iMAST Administrator, ARL Penn State, P.O. Box 30, State College, PA 16804-0030 or e-mail: bew3@arl.psu.edu. Parcel delivery address (UPS, FedEx, USPS): 225 Science Park Road, State College PA 16803.

DIRECTOR'S CORNER

both RepTech and ManTech categories. Ten years ago, the average project weighed in at around $187K – compared to today's approximate $410K. All 7 COEs have parallel concerns.

The biggest change in the ManTech paradigm has been the emphasis on the major acquisition platforms. Not a simple task when you really peel back the layers of implications. Saving funds on the construction of a new ship means working closely with the program office, the OEMs and, occasionally, the major subcontractors, as well as the technical authorities who oversee the Navy's drive for safety and mission effectiveness. None of the above comes free! Second, risk reduction has taken on much greater importance with the limitations on the ManTech budget. The process of identifying projects, justifying them with the program offices, and soliciting Navy or contractor technical cognizant participation isn't cheap either. Part of this risk reduction effort is the planning that goes into a project's transition potential. We wouldn't want to start a project that doesn't stand a fighting chance of actually making it onto the ship, plane or combat vehicle. While there are no guarantees, getting the right decision-makers on board early helps a lot! The end result of this program shift has – to ONR's credit – been higher overall success. Finally, technology has evolved! Ten years ago we were barely scratching the surface of Additive Manufacturing, Advance Manufacturing Enterprise tools, or robotics. As I'm sure you would agree, the new stuff always seems to be the most expensive.

What's coming in the next ten years? First, I think ONR will continue to support the major acquisition programs as long as the OEMs and new technology developments continue to support real returns on investment. Through ManTech, the taxpayer has invested in new technology and/or innovative applications – frequently earning it back within one or two ships. Investments in the sustainment world (RepTech) save money, mostly by preventing the expense from draining the sustainment accounts faster, i.e. – cost avoidance. Finally, the more technical we get, the more likely KISS will remain a viable engineering doctrine for a long time to come. Keeping it simple is how we first approach our various challenges. Complexity for complexity's sake is elegant – but expensive! We don't need that if the increase in combat capability or reliability isn't commensurately improved.

iMAST looks forward to the opportunities we have to be part of innovation in the manufacturing and sustainment worlds. Please let us know if you have constructive feedback or suggestions to help us with this enduring mission.

Tim Bair

★ MATERIALS PROCESSING TECHNOLOGIES ★ MECHANICAL DRIVE TRANSMISSION TECHNOLOGIES ★ LASER PROCESSING TECHNOLOGIES ★ COMPLEX SYSTEMS MONITORING TECHNOLOGIES ★ COMPOSITES MATERIALS TECHNOLOGIES ★ NAVY/MARINE CORPS REPAIR TECHNOLOGIES ★ MANUFACTURING SYSTEMS TECHNOLOGIES

Focus On Manufacturing Systems

Congestion Modeling for Outfit Sequencing

by Daniel A. Finke, Ph.D.

U.S. NAVY RELEASED PHOTO

Editor's Note: *This article represents efforts supported by the U.S. Navy's Manufacturing Technology program. Scheduling issues associated with large-scale products within confined installation space provides an opportunity to address near-minimum makespan schedule challenges. A framework to model these space challenges is being researched at ARL Penn State's Institute for Manufacturing and Sustainment Technologies. The developed framework has established an integrated methodology to model the effects of worker and activity space congestion during schedule generation. The installation project activities are constrained by precedence relationships and limited resource availabilities. Space is modeled as a special resource. The space modeling approach approximates the space required by the activities and uses those space requirements to calculate spatial conflicts. Space conflicts are incorporated via a congestion function, which increases the duration of the installation activities with overlapping spatial requirements, reflecting productivity losses due to interference. The congestion function is based on the conflict volume and the length of time the conflict occurs. By incorporating space requirements and considering the effect of spatial conflicts during schedule generation, a more realistic project schedule can be created that limits costly schedule delays attributed to less detailed planning practices. A prototype software application is developed from the framework to demonstrate the feasibility of the method. A hypothetical problem and a case study problem are solved using the application. The results show that considering spatial constraints increased the project makespan from 7% to 16% for the hypothetical problems and 35% for the case study problem.*

Large-scale products such as buildings, aircraft, and ships are constructed such that the structure is completed and then detailed installation of plumbing, electrical, ventilation, lighting, etc. is performed. As the internal space within the units becomes more confined, with the addition of components, and the amount of detail or finishing work increases (tasks that involve the installation of smaller pieces, but where there are generally more pieces to install), the coordination of work, resources, and space becomes increasingly more difficult. In addition, the number of functions that must be accounted for increases the complexity even further, in that additional trade groups (plumbing, electrical, etc.) are required to perform these detail or finishing work activities. Additional trade groups introduce additional work space congestion. The interior work space allocation problem requires the definition of additional space types. A three-dimensional representation of space requirements combined with the schedule[1] will need to be used to model the interior space planning problem.

Space allocation and scheduling has a major impact on the overall production schedule, and until recently it has been left to the manufacturing supervisors to react to these effects. Research in the building construction industry has recently begun to integrate space planning into the project planning phase of building construction. There is still a need for advanced tools and methods for practitioners to fully incorporate space planning into practice.

SPACE PLANNING AND SCHEDULING

A thorough examination of the current literature in spatial planning has revealed that the construction industry is the pioneer in interior space modeling and analysis.[2] Most other general large-scale product industries account for space in their production activities in one way or another, but usually just reduce space to an integer resource and plan it as they would any other resource in the Resource Constrained Project Scheduling Problem (RCPSP). Research in the construction industry has formalized spatial definitions and requirements and has proceeded to integrate these models into the planning process.

The interior space allocation problem arises in general large-product industries in confined spaces such as rooms or within buildings. Examination of this problem has primarily focused on multi-floor building construction with similar work content on each floor.[3,4,5] The problem has been approached by identifying the spatio-temporal conflicts and manually resolve them by changing either the spatial requirement or the schedule.[2] A deficiency in this line of research is the manual reconciliation, which could be rectified through the use of an algorithm. Other approaches to the problem include a tabu search approach,[6] and simulated annealing;[7] both approaches focus on minimizing the travel distance of resources to the work areas.

Performing work activities requires space to store raw materials, operational space for trade groups and equipment, and access to the workface[2] have condensed space into three categories: macro-level, micro-level, and paths. They define macro-level spaces as site level spaces that are used for storage, layout, staging, etc. Micro-level spaces are defined as the local spaces required to install the components. Paths are the spaces required for travel of labor, materials and debris to-and-from the worksite.

Since several trade groups are required in shipbuilding, inadequate planning and work management can often lead to work congestion. Thomas, Riley, et al[8] defined work congestion, identified the causes, and presented a case study to show the impact of work congestion on productivity. In addition, the authors discussed techniques to avoid work congestion on both macro- and micro-levels. They cited industry standards for nominal required space and provided empirical evidence that these standards may not be relevant for some types of activities.

4D MODELING

Researchers in the building construction industry have begun to develop a solution to the complex task of integrating spatial constraints into the planning phase.[10] This work couples computer aided design (CAD) information with schedule information to form a 4D (3D CAD + time) model.[9,10]

Heesom and Mahdjoubi[11] presented, discussed, and compared six tools that represented the state of the art in construction industry 4D modeling at the time. These tools advance the state of practice by providing more flexible and easy to use tools for manual rectification of congestion, however they do not explicitly enable scheduling of activities to minimize congestion or the impact that congestion has on the production schedule.

APPROACH

The methodology described here is defined by a framework of interconnected algorithms and methods that accept a network of activities and generate a near minimum makespan, resource-constrained schedule that considers the spatial requirements of the activities. The framework draws

PROFILE

Daniel A. Finke is an associate research engineer at The Pennsylvania State University's Applied Research Laboratory. He holds a Ph.D. in Industrial Engineering and an M.S. degree in Industrial Engineering and Operations Research from Penn State. He earned a B.S. degree in Industrial Engineering from New Mexico State University. He has contributed to several manufacturing systems modeling and analysis projects supporting process improvements in the shipbuilding industry. His research efforts include simulation-based optimization, project planning and scheduling decision support, and resource allocation optimization. Dr. Finke can be reached at (814) 865-5178, or by email <daf903@arl.psu>.

from several areas of research: resource-constrained project scheduling, heuristic search procedures, activity space generation, and congestion modeling.

RCPSP-S ALGORITHM FRAMEWORK

Figure 1 shows the flowchart of the main algorithm components that form the framework.

The framework describes the relationships between each of the algorithms used to solve the resource-constrained project scheduling problem with spatial constraints. The activities in the precedence network follow an activity model and are used to generate the spatial requirements defined in a space model. A heuristic search algorithm combined with a schedule generation algorithm iteratively searches through several possible schedules in pursuit of the minimum makespan schedule. The schedule generation algorithm interfaces with a congestion function to determine the impact of spatial conflicts on the duration of the activities. The heuristic search algorithm searches until the stopping criteria for the algorithm have been met and the schedule with the minimum makespan is reported to the user as the solution.

ACTIVITY MODEL

Each activity in the project is defined by a set of parameters that can be referred to as the Activity Model. The Activity Model is as follows:

- ID
- Type
- Required Resources
- Predecessors and Successors Lists
- Duration
- Assigned Resources
- Start Date
- End Date

The ID is the activity identifier that is used to differentiate it from other activities in the network. The activity Type describes the type of work the activity entails. Each activity also requires a number of resources. The Required Resources attribute defines both the number and type of resources that are required to complete the work. The activity network defines the predecessor relationships and this information is passed to the activity in the Predecessor and Successor Lists. The Duration attribute defines the nominal duration of the activity without any spatial interferences. The Assigned Resources attribute is designated as a result of performing the scheduling algorithm. This attribute contains the resource resource(s) that has been selected by the scheduling algorithm to fulfill the requirement. The Start and End Date attributes are also assigned by the scheduling algorithm and represent the exact start and stop dates of the activity.

SPACE MODEL

In addition to the information included in the Activity Model, each activity also requires space. The space requirements for the activities are generated using CAD

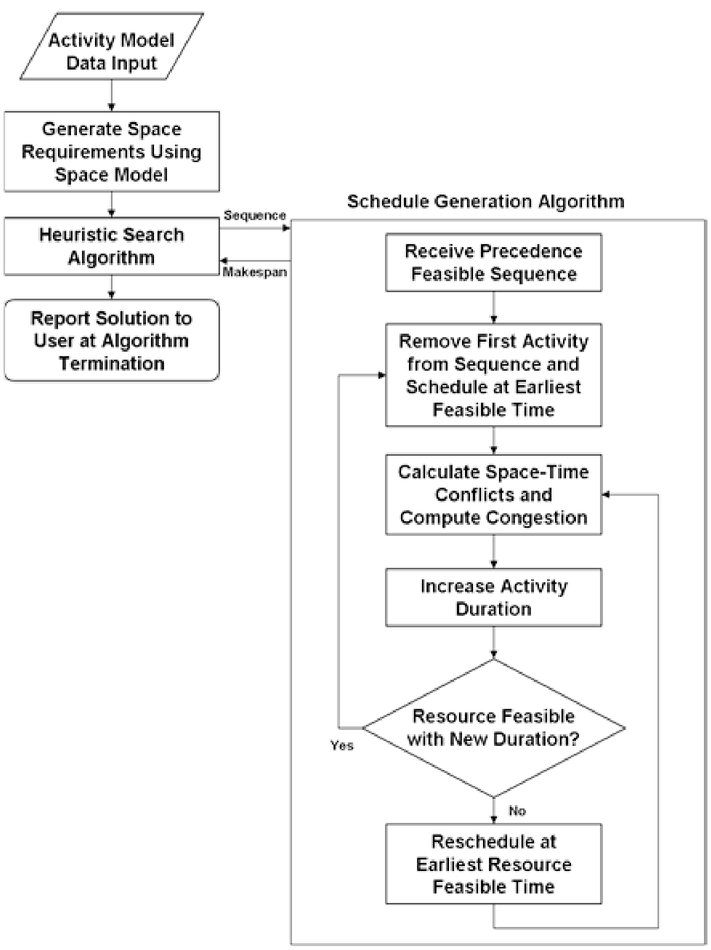


Figure 1. Framework flowchart.

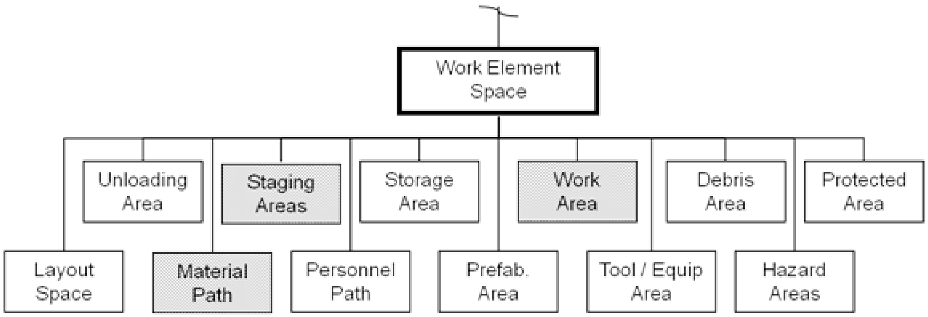


Figure 2. Support spaces and workspace geometry (Riley 1994).

data for each of the components. The CAD data is a detailed three-dimensional (3D) product model that includes detailed geometric information about where to place the installed components.

The initial step in accounting for space is to link the geometry to the activities. Linking the geometry to the activities is usually a manual process.[2] However, in some industries designers are working with planners to attribute the design elements with process information.[12]

In addition to the geometry of the components, each activity has support space requirements. Support spaces are areas within the unit that are used for travel of labor and materials, temporary storage areas for material, hazard areas, etc. A portion of the Types of Space in the Construction Space Model[3] is given in Figure 2 and shows the support spaces. All of the boxes under the Work Element Space box are considered support spaces, with the exception of the Work Area. Work Area space is considered execution space.

The spaces identified in Figure 2 represent all of the possible spaces for any general large-product industry. Specific scheduling problem instances in any industry may only include a subset of these activities to fully define the spatial requirements. In any specific implementation of spatial modeling, each space type should be evaluated to determine if it applies to the problem. Space generation algorithms are the focus of current research in the building construction industry.[2]

The detailed space requirement definition is termed the Space Model. In this paper we consider execution space, material path, and staging areas. The generation of execution space is accomplished by "growing" an envelope around the work pieces to provide access and adding rectangular prisms to represent workers. The material path is created by sweeping the component geometry along a path defined using the A* (A-Star) algorithm.[19] The staging area is a defined region outside the main entry to the unit.

SPACE MODEL

- Geometry of Available Space Within Unit
- Execution Space (Work Piece and Working Envelope)
- Support Space Definitions and Requirements

SPACE DEFINITIONS

Execution space is the space needed around the component for reach and access and the worker(s) to perform the work. The reach and access space of a component is modeled by generating the bounding box of the unit and increasing its size by 0.25 feet on all sides with a net increase of 0.5 feet in each dimension. The worker space is modeled as a rectangular prism that is 3'x3'x6' if the installation location requires the worker to be standing and 3'x3'x3' if kneeling.

Laydown space is the space needed at the entry point of the interior

Component B	Component A	Component Space	Execution Space	Travel Path Space	Laydown Space
	Component Space	Not Allowed			
		1			
	Execution Space	Allowed	Allowed		
		2	2		
	Travel Path Space	Allowed	Allowed	Allowed	
		2	2	3	
	Laydown Space	Allowed	Allowed	Allowed	Allowed
		2	3	3	3

Table 1. Spatial conflicts between space types.
1. Two component spaces overlapping would be a design flaw. This situation essentially results in two components occupying the same space. This type of space overlap is not allowed.
2. Spatial conflicts in this category will result in a duration increase for the installation of the activity currently being scheduled. The amount of increase will be determined through a congestion function.
3. The overlapping of these space types will have no effect on the activities. These overlaps involve transient space types that occur at the beginning of the activity. The overlaps that occur in this category will be on such a small time scale (minutes or hours) compared to the activity duration (days/weeks) that they can be accommodated without affecting the duration of the installation activity.

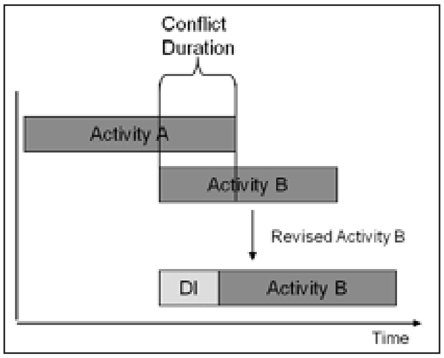


Figure 3. Execution space - execution space duration increase example.

space, i.e. door way, for the installation component to be transferred from one material handling device to another. In the case that the same material handling device can be used to move the component from outside the space to its installation location, this space simply provides a starting point from inside the space.

Travel path space is the space needed to get the installation component into its final position. In this work, the only concern was if the component was blocked and not the exact path that the component would take to arrive at the installation location. Table 1 shows the effect of spatial conflicts based on the types of space that are in conflict.

An example duration increase is presented in Figure 3. Notice that both Activity A and Activity B are scheduled to be performed during the same time period. Because the spatial requirements of each activity conflict with each other, the duration of Activity B is increased. The amount of duration increase is calculated by a composite congestion function that accounts for the conflicts between the various spaces.

The DI area on the revised Activity B indicates the duration increase caused by this type of spatial conflict.

The congestion function used in this approach draws from relevant literature to form a composite function based on conflict volumes of space types.

HEURISTIC SEARCH ALGORITHM

A genetic algorithm (GA) is used for the Heuristic Search Algorithm component of the framework. The GA method is derived from the permutation-based genetic algorithm method presented in[15,16] where the authors show that a priority-based encoding scheme and serial schedule generation scheme outperform the other encoding and decoding schemes.

The GA is used to generate sequences to be evaluated by the schedule generation algorithm. A GA uses a set of predefined parameters to govern the search. These parameters dictate how the initial generation of sequences is developed, as well as each subsequent generation. In addition, the parameters establish the criteria for the algorithm to terminate and present the solution to the user.

The schedule generation scheme used in this work is a serial schedule generation scheme (SGS) adapted from.[16] The serial SGS accepts a sequence from the GA and schedules the activity at the earliest resource feasible time. Once the activity is scheduled, the impact of space on the activity duration is estimated through the use of a congestion function. After all of the activities in the sequence are scheduled, the makespan of the schedule is reported back to the GA.

CASE STUDY-TORPEDO WEAPONS RETRIEVER

To demonstrate the feasibility of the methodology, a real-world example from the shipbuilding industry was modeled and solved using the developed framework. For this experiment, model geometry was provided and a subject matter expert was enlisted to help generate the activities and activity network. The Torpedo Weapons Retriever (TWR) is a tugboat sized vessel, approximately 75 feet long. It is used in shallow water for retrieval and towing operations. Most models of current vessels are not publicly releasable due to proprietary and/or subject to security controls. Because the models are not publicly releasable, it is difficult to conduct research that requires a model of a ship. To alleviate the difficulty, the shipbuilding industry, through the National Shipbuilding Research Program (NSRP), has modeled the TWR using CAD software and made the models available to the public for research.[17,18]

The pilot house of the TWR was chosen as the space for testing.

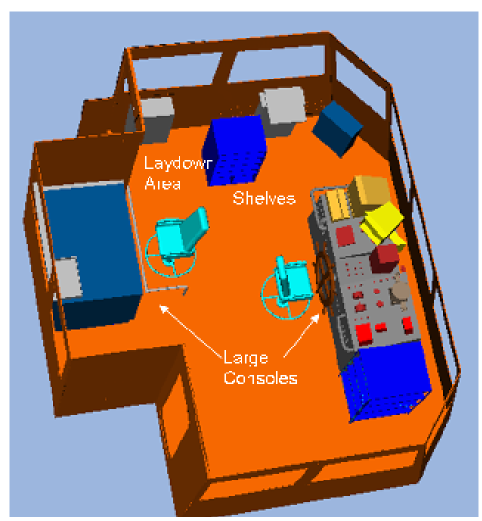


Figure 4. TWR pilot house model.

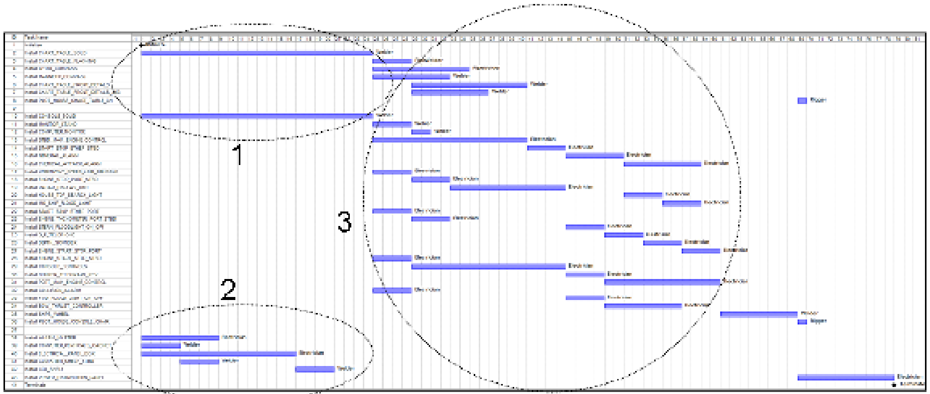


Figure 5a. TWR test case results without space. (Illegible graphic conveys the overall sweep of the program effort.)

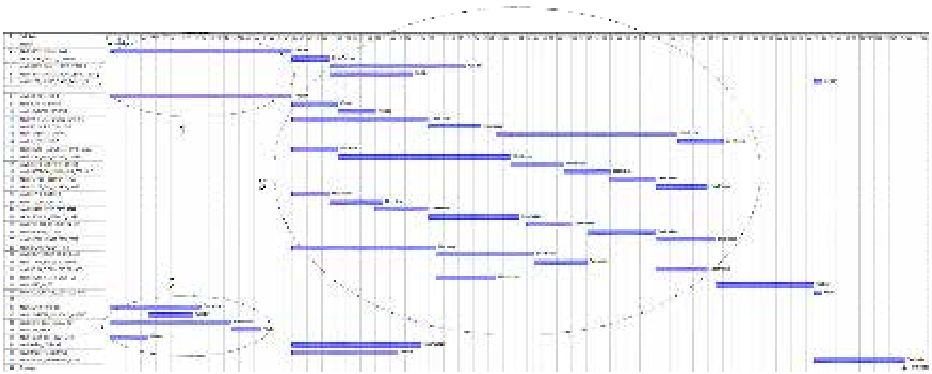


Figure 5b. TWR test case results with space. (Illegible graphic conveys the overall sweep of the program effort.)

There are 40 components installed in the pilot house. The pilot house is 19-feet long by 19-feet wide, with a height of 8-feet. Figure 4 shows the model of the TWR pilot house.

The components in the pilot house include several gauges and controls located on a large console. Several shelves are also installed along the top side of Figure 4. Another large console table with a railing and chair are installed on the left side of the unit. The laydown point for the components is assumed to be just inside the door in the upper left corner of the unit as depicted in Figure 4.

An installation activity was created for each of the 40 components and the geometry was linked to the activity. The activities were arranged into a network of predecessor relationships and durations. Resource requirements of the activities and resource pool sizes were estimated by a domain expert.

The network precedence structure was constructed using the logical layout of the components. For example, the large console must be installed prior to installing the gauges and controls that reside on it. Two main activities precede several subsequent activities that have no other predecessors. This type of network indicates that several activities can be performed in parallel.

The TWR Pilot House challenge was solved first without including space in the RCPSP and then again using the algorithm described in this paper. Figure 5a shows the results without space and Figure 5b shows the corresponding Gantt chart when space/congestion was included.

Results show that the duration for every activity that installed a component on the main console was increased due to congestion. This indicates that the used space factor component of the congestion function was responsible for the majority of the duration increases. For these activities, the working envelope of the used space factor was occupied at almost 50% for each of these activities. The main console accounted for the majority of the occupied space. The congestion caused by execution space and work in place space also caused the durations of these activities to increase. The worker space conflicted with the main console for the majority of the activities because of the location of the worker space in relation to the installation components. In addition, the results showed that laydown and travel path space conflicts had little effect on the activity duration increases.

When comparing the makespan of the problem without space and the problem with space, results showed an increase of 35% for the TWR case.

CONCLUSIONS

The framework was used as the basis for the development of a methodology that implemented specific algorithms for the various algorithmic components of the framework. The implemented methodology uses a genetic algorithm to generate sequences of activities and guide the search. A serial schedule generation scheme (tradition RCPSP solution technique) that considers space is used to schedule the activities. The spatial requirements of the activities are used to estimate the congestion by calculating spatial conflict volumes and translating them into a duration increase through a congestion function. The congestion function is a parameterized set of equations that can be modified according to the characteristics of the problem domain.

The thesis of this work is that a more accurate estimation of project schedule makespan can be calculated by modeling the space required by the activities and using a congestion function that increases the nominal activity durations based on the spatial conflicts of the activities. The main contribution to the body of research in this field is the integrated solution framework that includes activity spatial requirements into the resource-constrained project scheduling methodology.

An example problem and a real world case study were solved using the methodology to demonstrate the approach. The results showed that considering spatial constraints increased the makespan from 7% to 16% for the example problems and 35% for the TWR case study problem.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the Office of Naval Research and its Navy Manufacturing Technology (ManTech) Program, which supports ARL Penn State's Institute for Manufacturing & Sustainment Technologies (iMAST) Center of Excellence. Navy ManTech efforts facilitated the in-house development of the modeling tools discussed within this article. These tools directly benefit the U.S. Navy-Marine Corps team – and beyond.

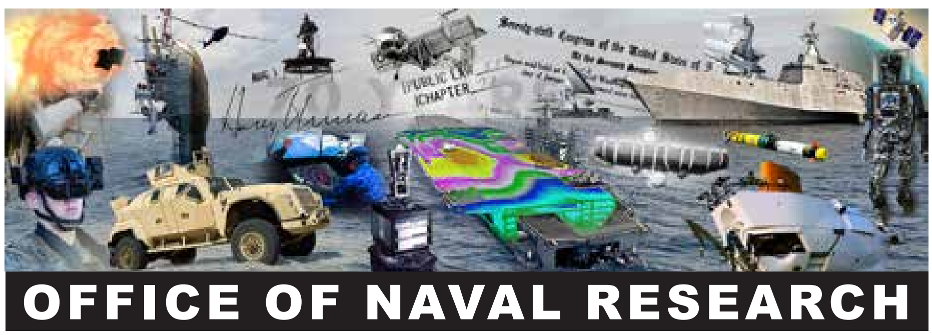
REFERENCES

1. Ahmed, M. U. and P. S. Sundararaghavan (1990). "Minimizing the Weighted Sum of Late and Early Completion Penalties in a Single Machine." IIE Transactions 22(3): 288-290.
2. Akinci, B., M. Fischer, et al. (2002). "Automated generation of work spaces required by construction activities." Journal of Construction Engineering and Management 128(4): 306.
3. Riley, D. R. (1994). Modeling the Space Behavior of Construction Activities. Architectural Engineering, The Pennsylvania State University. Ph.D.: 295.
4. Riley, D. R. and I. D. Tommelein (1996). "Space planning tools for multi-story construction." Congress on Computing in Civil Engineering, Proceedings: 718.
5. Riley, D. R. and V. E. Sanvido (1997). "Space Planning Method for Multistory Building Construction." Journal of Construction Engineering and Management 123(2): 171-180.
6. McKendall, J. A. R. and J. R. Jaramillo (2006). "A tabu search heuristic for the dynamic space allocation problem." Computers & Operations Research 33(3): 768.
7. McKendall, A. R., J. S. Noble, et al. (2005). "Simulated annealing heuristics for managing resources during planned outages at electric power plants." Computers & Operations Research 32(1): 107.
8. Thomas, H. R., D. R. Riley, et al. (2006). "Fundamental principles for avoiding congested work areas-A case study." Practice Periodical on Structural Design and Construction 11(4): 197.
9. Adjei-Kumi, T. and A. Retik (1997). Library-based 4D visualization of construction processes, London, Engl, IEEE.
10. Webb, R. M., J. Smallwood, et al. (2004). "The potential of 4D CAD as a tool for construction management." Journal of Construction Research 5(1): 43.
11. Heesom, D. and L. Mahdjoubi (2004). "Trends of 4D CAD applications for construction planning." Construction Management and Economics 22(2): 171.
12. Cahill, P. D. (2006). "CAD-plan connector." Journal of Ship Production 22(3): 113.
13. Mallasi, Z. (2006). "Dynamic quantification and analysis of the construction workspace congestion utilising 4D visualization." Automation in Construction, 15(5), 640.
14. Thabet, W. Y. and Y. J. Beliveau (1997). "SCaRC: Space-Constrained Resource-Constrained scheduling system." Journal of Computing in Civil Engineering 11(1): 48.
15. Hartmann, S. (1998). "Competitive genetic algorithm for resource-constrained project scheduling." Naval Research Logistics 45(7): 733.
16. Hartmann, S. and R. Kolisch (2000). "Experimental evaluation of state-of-the-art heuristics for the resource-constrained project scheduling problem." European Journal of Operational Research 127(2): 394.
17. Benthall, L., T. Briggs, et al. (2004). "Enabling interoperability between US shipyards." Journal of Ship Production 20(2): 90.
18. Gischner, B., P. Lazo, et al. (2006). "Enhancing interoperability throughout the design and manufacturing process." Journal of Ship Production 22(3): 172.
19. Hart, P. E.; Nilsson, N. J.; Raphael, B. (1968). "A Formal Basis for the Heuristic Determination of Minimum Cost Paths". IEEE Transactions on Systems Science and Cybernetics SSC4. 4 (2): 100–107. doi:10.1109/TSSC.1968.300136.

PennState
Institute for Manufacturing and Sustainment Technologies

ONR Legacy of Innovation

The Office of Naval Research recently celebrated its 70th year of innovation with a Legacy of Innovation: Building the Future Force themed exhibit event at the Pentagon. For seven decades, ONR has been leading the discovery, development and delivery of technology innovations for the Navy and Marine Corps. During August of 1946 Congress mandated a new military command to identify and cultivate forward-looking science and technology capabilities to ensure the superiority of U.S. warfighters. The establishment of the Office of Naval Research marked the first time a peacetime organization would use government funds to support civilian science and technology research at universities, laboratories and businesses. That is also the year iMAST's parent organization, the Applied Research Laboratory at The Pennsylvania State University was officially sanctioned as a U.S. Navy research center of excellence (later morphed into a University Affiliated Research Center, or UARC, designation). Since that year the Naval Research Enterprise has played a pivotal role in many of the most important discoveries and inventions – from the earliest computer systems and software, to the exploration of the ocean's depths, to new materials and sensors that have been integrated into everything from household items to warships.



MDMC Visit

ARL Research R&D Engineer Clark Moose (foreground) briefs MDMC/MCLC visitors on composites process and non-destructive inspection technologies in ARL's Advanced Composites Laboratory. From left to right: Mr. Brett Cleveland (MDMC Director of Operations); Colonel Eric Livingston USMC (Commanding Officer, MDMC) and Colonel Mike McWilliams (Operations Officer, MCLC)

Senior members of the Marine Depot Maintenance Command (MDMC) and the Marine Corps Logistics Command (MCLC) recently visited ARL/iMAST to gain insight on repair technology enhancements that support MDMC's mission to repair, rebuild, and modify all types of Marine Corps ground combat and combat service support equipment. MDMC also provides additional support relative to: Inspection and Repair Only as Necessary on all Marine Corps equipment; preparation for shipment and care-in-store support for remote storage activity. Support also provides calibration support to various Marine Corps customers, and conducts special projects as directed. Co-located at both Marine Corps Logistics Bases Albany (GA) and Barstow (CA), the depot provides critical support within the very fluid operational readiness environment the Marine Corps is shouldered with. iMAST is the designated Navy-Marine Corps lead on the Office of Naval Research's repair, overhaul, and sustainment initiative. It is chartered to apply new emerging technologies to improve the capabilities of the repair community, as well as enhancing repair processes and the affordability of repair facilities. For more information on this program contact the iMAST director (Tim Bair).

RepTech Working Group members tour the Penn State FAME facility.

RepTech Working Group Meeting

iMAST holds the distinction of leading the Navy-Marine Corps team's repair, overhaul and sustainment initiative. In concert with that role iMAST recently hosted a semi-annual Repair Technology Working Group meeting to discuss current and future repair technology issues facing Navy and Marine Corps depots, shipyards and supply centers, as well as DoD contractor facilities. The meeting was attended by ONR, NAVSEA, NAVAIR and Marine Corps representatives. All current sustainment-based projects were briefed as well as current acquisition saving ManTech projects offering potential application within the depots and shipyards. Newly proposed projects were also briefed including: NULKA Decoy Repair, development of a portable hatchable Cold Spray repair unit, DDG uptake repair, and a potential ship's hull cutting/welding system. In addition to the briefings, attendees were taken on a tour of the CIMP-3D laboratory to examine potential additive manufacturing applications that can support the repair and sustainment domain. The group also visited Penn State's Factory for Advanced Manufacturing Education (FAME) within Penn State's Department of Industrial and Manufacturing Engineering. This 10,000-square foot-integrated high bay laboratory is for teaching and research. The main objective of FAME is to reinforce the principles and theoretical concepts taught in the classroom, as well as to introduce students to the equipment, procedures, and difficulties associated with common engineering processes. The lab has most of the elements of a real manufacturing facility. It houses many diverse manufacturing processes including casting, welding, machining, forming, injection molding, and assembly systems. In addition, the lab includes automated high-tech facilities dealing with robotics and assembly featuring computer integrated manufacturing cells and robots. Penn State's Industrial Engineering Department consistently places in the top five industrial engineering schools in the nation.

COVER ARTICLE

Continued from Page 1

US Navy Released Photo

In command, Admiral Hahn deployed to the Caribbean Sea and Pacific Ocean, and conducted an Engineering Overhaul in Portsmouth, New Hampshire.

Since becoming an acquisition professional in 2007, he has served as Joint Test and Evaluation test director and program manager, Advanced Submarine Research and Development. He has also served as major program manager, Submarine Combat and Weapon Control Systems program.

In addition to his Bachelor of Science degree in mechanical engineering from the U.S. Naval Academy, Admiral Hahn holds a Master of Business Administration degree from George Mason University and has completed the Massachusetts Institute of Technology Seminar XXI program in International Security Affairs.

Admiral Hahn's personal awards include Defense Superior Service Medal, Legion of Merit, Defense Meritorious Service Medal, the Meritorious Service Medal (three awards), the Navy and Marine Corps Commendation Medal (four awards), the Navy and Marine Corps Achievement Medal and various campaign and sea service awards.

PennState
Applied Research Laboratory

P.O. Box 30
State College, PA 16804-0030
(814) 865-6531

There's no shortage of good ideas, I'll say that, so where I'm trying to focus is the much less exciting process development, so that when you have a genius idea, what's the quickest way to make that thing real?
—Admiral John Richardson USN, Chief of Naval Operations

CALENDAR of EVENTS 2017

10-12 Jan	Surface Navy Association	**Crystal City, VA
7-9 Mar	NSRP All Panel Meeting	**Charleston, SC
3-5 Apr	Navy League Sea-Air-Space Expo	**National Harbor, MD
9-11 May	AHS Forum 73	Ft. Worth, TX
4-8 Jun	45th North American Manufacturing Research Conference	Los Angeles, CA
20-22 Jun	Mega Rust	**Newport News, VA
20-21 Jul	ONR NAval Future Force S&T Expo	**Washington, DC
4-7 Dec	Defense Manufacturing Conference 2017	**Tampa, FL

** Visit iMAST booth