Decision Support System for Production Planning in the Ship Repair Industry

Denis Pinha and Rasphal Ahluwalia

West Virginia University
Morgantown, WV, USA

Corresponding Author's Email: rashpal.ahluwalia@mail.wvu.edu

Author Note: Mr. Pinha is a Ph.D. candidate in the Department of Industrial and Management Systems Engineering (IMSE) at West Virginia University. He has over ten years of experience in production planning and in developing customized solutions for large multinational corporations. Dr. Ahluwalia is a professor in the IMSE department. He has several years of experience in production planning, process planning, systems engineering, quality, and reliability engineering. He is a fellow of the American Society for Quality (ASQ), a life senior member of the Institute for Electrical & Electronics Engineers (IEEE), an ASQ Certified Software Quality Engineer (CSQE), a registered Professional Engineer (PE) in West Virginia. Dr. Ahluwalia serves on several editorial boards and professional committees.

Abstract: All ships and offshore platforms, however large or small, undergo scheduled or unscheduled repair and maintenance. The bidding process for a ship repair job is highly competitive and global in scope. The ship repair industry is also prone to significant risks due to high levels of capital investment in skilled labor, specialized equipment, and facilities such as dry docks. Tradition decision support tools have been utilized by this industry for mid to long-term planning. These tools organize the system as a collection of cost centers and attempt to minimize cost at each center. This paper proposes a decision support system for short term planning. It is oriented towards day to day decision making, with an objective of maximizing system throughput and minimizing total project cost. Such an approach avoids unnecessary internal completion between cost centers, resulting in fewer delays and resource overloading. The proposed decision support system utilizes a common corporate database to share information between stake holders.

Keywords: Production planning and scheduling, supply chain management, ship repair and maintenance, decision support system.

1. Introduction

Ship repair and maintenance is a complex and costly activity largely due to large distances between ship location and ship repair facilities, high capital investment in specialized equipment, such as cranes and dry docks, and relatively short lead times. Planning for such tasks is further complicated due to scarcity of skilled personnel. The ship repair and maintenance industry is an important source of revenue for several countries, particularly the developing countries. It is also one of the largest consumers of energy. In 2013, a study presented at the Ship and Offshore Repair Journal (Thorpe and Bartlett, 2013) claimed that per capital energy consumption continues to climb and the pace of increase is largely due to activities in the developing countries. In May 2013, MARAD released a report describing economic importance of the US shipbuilding and ship repair industries (MARAD, 2013). The report indicated that this industry creates high quality jobs and impacts all States in the US. It also impacts other industries such as mining, energy, manufacturing, and transportation. In order to meet increasing level of demands for ship and offshore platforms repair services, several shipyards around the world have invested in ship repair facilities. Yulian Dockyards is one of the largest repair shipyards in China (Benkley, 2007).

Several project management and decision support tools have been developed to obtain higher levels of efficiencies for ship and offshore platform repairs. Thus far, these tool have had very limited success. Dlugokecki et al. (2010) proposed a project management approach to shipbuilding and ship maintenance through the delivery of a web-based system using planning and production engineering techniques. Mourtzis et al (2005) integrated different stakeholders in the repair planning process. Heuristic dispatching rules have also been utilized. The resource modeling considers a group of workers as one resource and each one has specific skills, such as, painting, welding, etc., they did not allow resource sharing when skills are interchangeable. Chryssolouris et al (2004) utilized Internet-based supply chain management techniques. Different authors have proposed different techniques. Thus far, no standard procedures have been established.

2. System Description

Repair shipyards commonly comprise floating docks and dry docks. Docks are the most valuable and expensive resource of a repair shipyard. Proper utilization of docks can be the difference between profit and loss. The less time a ship spends in the dock, greater the flow of services, and consequently, greater the profit (Pinha, 2011). Cranes are the second most valuable resource at a ship yard. They are utilized by almost all work teams, along with other material handling resources such as forklifts and trucks. Additional resources include, plasma cutting, pipe bending, welding machines, and skilled worker, such as welders, painters, electricians, etc. Table 1 shows some of the resources organized by work teams, machines, tools, and material handling devices (Pinha et al., 2011).

Table 1. Types of Resources

Work Teams	Machines	Tools	Material Handling
Mechanical	Plasma Cutting	Hydro-jet pumps	Forklift
Structure	Pipe bending	Paint pumps	Trucks
Paint	Welding Machines	Hydraulic pumps	Cranes
Sand-blasting	Tube resources	Sand-blasting pumps	Pulley

Resources are grouped according to the task at hand. Once the ship is docked, resources are brought (fixed position layout) to the ship to carry out the various task. Vast majority of repair and maintenance services are carried out manually. Typical services include: a) docking, b) hand scraping, c) high pressure fresh water jet cleaning, d) painting, e) tank cleaning, f) steel work, g) repair of ship's structure, h) repair of ship's propulsion system, i) piping repair, j) valve repair, k) repair of electrical system, l) undocking, and m) testing at sea. These services are further broken down into several hundred individual tasks. The project manager is responsible for production planning, scheduling, and efficient allocation of resources to tasks. The production planning and scheduling of tasks is difficult due to finite resources and uneven flow of repair orders (Pinha and Ahluwalia, 2013), (Dlugokecki et al., 2010), (Mourtzis, 2005), (Wullink et al., 2004), (Van Dijk, 2002), (Chryssolouris, 1999), (Chryssolouris et al., 2004), (De Boer, 1998), (De Boer et al, 1997).

3. Current Approach

A ship repair facility is typically organized by docks. Each dock has a dock manager. The dock managers are rewarded for efficient operation of their dock. They schedule tasks on their docks using a simple spreadsheet or Microsoft Project software. The dock managers compete for finite resources with other dock managers. It results in optimizing operations at an individual dock, while sub-optimizing the overall projects. Such an approach leads to schedule slippage and cost overruns (Pinha and Ahluwalia, 2013), (Van Dijk, 2002). In addition, there is lack of communication among stakeholders, such as dock managers, customers, and suppliers. Efficient operation of such a system is dependent on dock mangers resourcefulness and skill level of the workforce. In addition, the dock managers do not share lessons learnt due to internal competition.

According to (Van Dijk, 2002), the traditional time-driven approaches such as the Critical Path Method (CPM), have several shortfalls for the ship repair industry. He proposed a multi-project approach with simultaneous consideration of time and capacity. It is an extension of the approach proposed by (De Boer, 1998), (De Boer et al., 1997). Wullink's work (Wullink, 2005), (Wullink et al., 2004) deals with resource loading under uncertainties. He utilized a scenario based approach and the concept of robustness to deal with demand and capacity uncertainties. He did not consider precedence relationships, release dates, and rush orders. Dlugokecki (Dlugokecki et al., 2010) proposed a decision support approach inspired in Ballard (Ballard, 2000). His work showed improvement in cost savings and higher level of productivity for building new ships. They did not describe application of their work to ship repair. Ballard and Choo (Ballard, 2000), (Choo, 2003) presented a resource model to manage construction projects. Their model lacks complexities of the ship repair industry.

The scheduling policies and the concept of robustness were addressed by (1- Feng et al., 2012), and (2- Feng et al, 2012). Briefly, their approach covered buffer capacity, arrival rate based on a Poisson process, operation time and setup time based on the Exponential distribution. Their approach provided good scheduling performance for the developed criterion. They utilized seven heuristic dispatching rules to determine the overall best performance. However, basic production issues, such as, operation precedence and multiple resources required to complete a task were not covered. They demonstrated their approach on a single machine producing several products.

This paper focuses on the work done by (Mourtzis, 2005), (Chyrssolouris et al., 2004), and (Chyrssolouris, 1999). These authors integrated different stakeholders in their planning process. They took a systems approach to planning and utilized state of the art information technology tools such as heuristics and event-driven simulation to allocate resources. They identified major differences between production planning and scheduling for the shipbuilding industry vs. the ship repair industry. Some of the differences are types of facilities, types of equipment, worker skill levels, work flow patterns, shifting priorities, cost and delivery schedule (Chabane, 2004). Authors (Charris and Arboleda, 2013), (Mello and Strandhage, 2011) worked on supply chain management for shipyards. Zhou (Zhou et al., 2013) proposed solutions for repairing war ships; however, their work lacked several real issues of the ship repair industry. Papakosta (Papakostas et al., 2010), (Framinan and Ruiz, 2012, 2010), (Moghaddam and Usher, 2011), and (Yamashita et al, 2014) proposed other approaches. Papakosta's work was based on (Chryssolouris and Dicke, 1992), (Chryssolouris et al., 1992, 1991), (Chryssolouri, 2005) to deal with maintenance of airplanes

4. Proposed Approach

Current production planning and scheduling activity at shipyards are static in nature and are based on Microsoft Excel or Microsoft Project software, often resulting in cost over runs, schedule slippage, and low throughput. This paper proposes a dynamic approach to production planning and scheduling. It will enable project managers to adapt to uncertainties in repair orders, resources, and priorities. The approach is based on event driven simulation for a finite capacity system, and the use of heuristics to address the needs of a particular facility.

Previous work by Ahluwalia and Pinha (Ahluwalia, 2006, 2005, 2003) developed guidelines, software, and database for ship dismantling. Pinha and Ahluwalia (Pinha, 2013) also presented a schema for an enterprise database for the ship repair industry. Pinha (Pinha et al., 2011) proposed a theoretical foundation for utilizing Supervisory Control Theory (SCT) for planning and scheduling ship repair activities. The methods presented in this paper interface with the enterprise database to generate reports for the management. It will enable management to conduct "what-if" type analysis. Managers will be able to determine impact of a decision on cost, priorities, and schedule, prior to the decision being executed. Preliminary schema for a database was presented in (Pinha and Ahluwalia, 2013). Thus far, forty database tables and their fields have been identified. The database was designed to store data on capacity, engineering, order status, task status, operational decisions, and management reports.

4.1 System Architecture

Major components of the system are shown in Figure 1. The key issue is, given the status of the resources, what affect does a particular decision have on the system? It is proposed that impact of a decision be determined by simulating the activities and producing reports on: 1) resources utilization (loading/capacity), 2) schedule, 3) procurement, 4) throughput, tardiness and earliness analysis, 5) financial impact, 6) order lead times, 7) energy consumption, and 8) resource plan robustness. Such information can change priorities, capacity levels (hiring temporary workers, authorizing overtimes, preventive/predictive maintenance), subcontracting of critical tasks, etc. The system should be able to address project manager's concerns, such as, a) workforce skill and flexibility, b) classification of resource by worker skill levels, c) task precedence order, d) alternate approaches to performing a task, e) impact on safety, f) impact on the environmental, g) impact on energy consumption, etc. Table 2 summarizes possible inputs and responses by the system.

4.2 Event-Driven Simulation

Event driven simulation is a general approach in which the internal operations of the system are modified by external events. The modifications can be instantaneous or after a certain time interval. The proposed methods assume an event to be a deterministic variable. The methods also assume finite capacity of resources, such as workforce, machines, tools, material handling resources (e.g. trucks, cranes, forklifts), and materials (e.g. high strength steel, bronze bushing). Finite Capacity Scheduling (FCS) can be described as allocation of resources to perform tasks during a given time interval, subject to available resources. Details of FCS are provided by (Pinedo, 2012), (Costa et. al., 1998-1992). Since the capacity of resources is limited, dock managers compete for resources. Therefore, usually there is a queue of tasks to be performed by a particular resource. The proposed methods handle queues dynamically by applying dispatching rules and operational decisions.

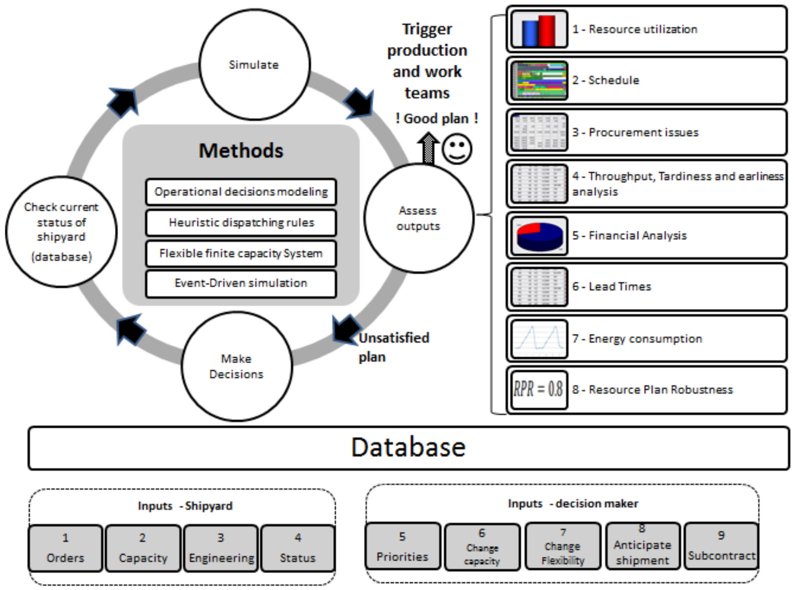

Figure 1. System Architecture

Table 2. Inputs- Shipyard

	Inputs	Description	Simulator
Shipyard data	1. Orders	Includes due date, client details, delay penalties, ship description, estimated dock date, and undock date.	What tasks need to be performed to fulfill the order?
	2. Capacity	Includes status of machines, tools, workers, material handling resources, and worker skills.	Does the shipyard have the capacity to perform the tasks?
	3. Engineering	Includes services provided, operation times, bill of materials, operation precedence, and constraints.	How will the tasks be performed?
	4. Status	Percent of tasks completed, man hours of tasks completed, man hours of tasks scheduled.	What is the status of tasks?
Decision Maker Data	5. Priority	Includes a prioritized list of tasks that need to be performed in order to fulfil an order.	What are other alternative to fulfill the order?
	6. Change capacity levels	Simulate impact of overtime, adding new worker skills, switching work between shifts	
	7. Change capacity flexibility	Simulate impact of utilizing workers with excellent, and good skills, and utilizing alternate resources.	
	8. Supplier schedule	Simulate impact of different supplier delivery dates on schedule, cost, and resources.	
	9. Subcontract	Simulate option to subcontract some tasks if limited by capacity or worker skill level.	

4.3 Estimation of Completion Time

One of the main gaps in the literature is how to represent capacity of repair shipyards. If the capacity is not well described, the results will be unreliable. The work force teams listed in Table 1 are usually grouped according to cost centers. This is mainly due to the traditional decision support approach to individually deal with time, cost and capacity. It results in complicating the planning process and ultimately it has a negative impact on productivity. An improved approach to capacity modeling is as follows:

1) Workers throughout the shipyard can be categorized according to their main skills. A count can be maintained for each skill type. Table 3 shows an example of such information. Information about interchangeability of workers can also be maintained.

Table 3. Skill Profile

N	Skill	Qty	N	Skill	Qty	N	Skill	Qty	N	Skill	Qty
1	Welder	300	6	Mechanical	32	11	Crane operation	10	16	Ship docking	20
2	Cutter	100	7	Electrical	60	12	Forklift operation	100	17	General labor	100
3	Blowtorch	100	8	Blasting	50	13	Carrier	100	18	Security office	50
4	Boiler	50	9	Painting	60	14	Scaffolding	100	19	Firefighting	100
5	Assembly	100	10	Plumbing	30	15	Carpenter	100	20	Quality Control	50

2) Work teams should be formed dynamically by grouping skills required for a given task, e.g. if a task needs a welder, cutter, and a blow torch operator, and if a worker has all of these three skills, then the team will consist of only one person. However, if one worker has two skills and another worker has the third skill, then the team will consist of two workers. The manager ultimately defines the number of workers for each task. Dynamic management of teams offers scheduling flexibility. Table 4 shows a dynamic team matrix. Team 1 is able to weld, cut, and perform blowtorch operations, whereas Team 2 can cut and perform blowtorch operations. Each repair facility will maintain data as shown in Table 4. An "O" in Table 4 indicated team skills. Number of workers in a team is shown under the "Qty" field in Table 4. Such an approach provides scheduling flexibility.

Table 4. Team Matrix

	Welder	Cutter	Blowtorch	Boilers	Assembler	Mechanic	Qty
Team 1	O	O	O				150
Team 2		O	O				60
Team 3		O		O			10
Team 4			O		O	O	10

3) Tables similar to Tables 4 can be created for other resources. Number of hours required for a task and in which shifts a team works will depend upon shipyard strategy. Suppose team 1 has 150 workers and skill welder can be only required at shift 1, whereas cutter and blowtorch skills is required for all three 3 shifts. Hence, the welder skill from team 1 will be not available for shifts 2 and 3, even though workers are there with these three skills. In case, these skills do not differentiate in terms of shifts, information for the entire team regarding to work shift is enough. Table 5 shows the final input information for team 1 regarding its skill´s flexibility versus capacity (shift), grade for productivity, and grade for quality. The same logic can be applied for all teams.

Table 5. Operator Skill Classification

Skills	Shift	Time	Quality
Welding	1	Excellent	Good
Cutting	1, 2, 3	Good	Satisfactory
Blowtorch	1, 2, 3	Satisfactory	Excellent

The proposed method utilizes a dynamic approach to matching skills with tasks, instead of the typical pre-determined approach. It provides flexibility in resource allocation and opportunities to reduce costs and increase throughput. The proposed method searches for skills instead of resources as suggested by (Van Dijk, 2002). Dock managers use the common decision support approach of using pessimistic time (a), most likely time (m), and optimist time (b), to estimate task completion time. Assuming a beta distribution, the task completion time is estimated by $\mathrm{tf} = (\mathrm{a} + 4\mathrm{m} + \mathrm{b})/6$. However, the expected task completion time is strongly impacted by the resources utilized to carry out the tasks. In the ship repair industry, a task can be carried out by a variety of skills and resources. This paper proposes a simulation approach to matching skills and resources. Such an approach will enable management to consider factors such as machine efficiency (E), operator experience (OE), weather conditions (W), and local factors (LF), to estimate task completion time as shown in equation 1.

$$ts = \frac{a + 4m + b}{6 * E} * OF * W * LF \qquad (1)$$

4.4 Operational Decision Making

Operational decisions making involves tactical knowledge of shipyard issues. The routine operational decisions have higher priority than dispatching rules because operational decisions strongly impact dispatching rules making them sometimes innocuous. There is a need for rapid decision making due to changes in priority, capacity levels, capacity flexibility, anticipate shipment from suppliers and subcontracts. The simulation approach allows for flexibility in operational decision making, as opposed to having a single global rule for the entire shipyard (Chryssolouris, 1999), (Chryssolouris et. al., 2004) and (Mourtzis, 2005). In addition, different rules should be developed for each resource, because rules for welding resource do not apply to the painting resource.

4.5 Management Reports

The simulation approach can analyze impact of routine decisions on system throughput and cost. Table 6 lists some of the reports that can be generated for dock managers and other stakeholders.

This paper proposes the concept of Resource Plan Robustness (RPR). It is based on the work done by (Wullink, 2005), (Yamashita et al., 2007), (Leus et al., 2011), and (Artigues et al., 2013). The decision makers can utilize this information, along with prior knowledge of orders, to estimate demand, as opposed to utilizing a probabilistic approach. The proposed system deals with short-term production planning. It estimates possible arrival of new orders (ships coming in). Use of a probabilistic approach to estimate future demands adds additional uncertainty to the project. Hence, $\mathrm{PD}_{r,t}$, TPDr, $\mathrm{ACr,t}$ are computed according to equations (2), (3) and (4) respectively. The available capacity (AC) assumes two different values depending upon the time horizon.

Table 6. Management Reports

Outputs (Reports)	Description	Simulator
1. Resource Utilization	Loading required and available capacity for each resource during the simulation time horizon.	What can be assessed to verify if the current plan will meet current goals?
2. Schedule	Order in which tasks must be performed by resources to order to meet the current goals.	
3. Procurement issues	Materials that will delay the start time of a task.	
4. Throughput and Tardiness	Estimated delivery data vs. the deadlines agreed upon with the customer.	
5. Financial	Impact of a decision on total cost, operational cost and schedule.	
6. Lead times	Time needed to finish all tasks to meet order deadline.	
7. Energy consumption	Estimate of energy cost of a decision.	
8. Resource Plan Robustness	An index to measure the robustness of a plan, with respect to available capacity.	

$$PD_{r,t} = \sum_{p=1}^{\mathrm{NPO}} \sum_{k=1}^{\mathrm{NTPp}} pd_{pkrt} \; (\forall r \in R, \forall t \leq \mathrm{THPO}) \qquad (2)$$

$$TPD_r = \sum_{t=0}^{\mathrm{THPO}} PD_{r,t} \; (\forall r) \qquad (3)$$

$$AC_{r,t} = \begin{cases} c_{rt} + o_{rt} - \sum_{i=1}^{NO} \sum_{j=1}^{NT_i} c_{ijrt} \; (\forall r \in R), t \leq \mathrm{THO} \\ c_{rt} + o_{rt} \; (\forall r \in R), \mathrm{THO} < t \leq \mathrm{THPO} \end{cases} \qquad (4)$$

Resource Robustness (RR) can be computed by equation (5). It is different from (Wullik, 2005), because it splits the numerator into two terms in order to deal with the available capacity that changes with time. The first term deals with THO and the second term deals with THPO. The first term is the sum of the minimum of $AC_{r,t}$, and $PD_{r,t}$. The second term in the numerator is a minimum of $AC_{r,t}$ and ($PD_{r,t} + CD_{r,t}$) because prospective demand and current demand come to play at the same priority level. The Resource Plan Robustness (RPR) is computed by equation (6). A value of 0.8 is used for illustration purposes. The closer RPR is to one, the more capable the current plan is to adapt to prospective orders.

$$RR_r = \frac{\sum_{t \leq THO} \min\left(AC_{r,t}, PD_{r,t}\right) + \sum_{\mathrm{THO} < t \leq \mathrm{THPO}} \min\left(AC_{r,t}, PD_{r,t} + CD_{r,t}\right)}{TPD_r} \quad \forall r \; (5)$$

$$RPR = 0.8 = \frac{\sum_r RR_r}{\sum_r TPD_r} \quad (6)$$

The RPR analysis is performed to verify how robust the current plan is with respect to uncertainty of future orders. Robustness index taken in isolation, without other outcomes does not provide accurate assessment. The overall plan robustness (PR) can be determined by simulating several scenarios, and assess the results from the multi-objectives criteria. Energy consumption in a shipyard has a major impact on cost and the environment. Operational decisions, such as, overtimes, hiring of temporary workers, affect energy consumption. Therefore, energy cost is taken into account to verify if a decision is cost effective. Since each task consumes energy, a report on energy consumption is necessary. Sum of Worker Cost (WC), Material Cost (MC), Resource Cost (RC), Over Time Cost (OTC), Tardy Cost (TC), Holding Cost (HC), Setup Cost (SC), Sub-Contractor Cost (SCC), Procurement Cost (PC), and Energy Cost (EC) can provide an estimate operational cost. Equations 7, 8, and 9 quantify the impact of an operational decision on operating profit.

Gross profit (GP) = Revenues – Fixed Costs (7)

Operational Cost (OC) = WC + MC + RC + OTC + TC + HC + SC + SCC + PC + EC (8)

Operating Profit = GP – OC (9)

5. Conclusions

This paper proposes the use of event driven simulation (for finite capacity systems) for short term planning of ship repair and maintenance tasks. The proposed approach is able to access risks and costs associated with operational decisions. It is able to respond to uncertainties and has the ability to simultaneously consider complex constraints, and adapt to the local environmental factors.

6. References

Ahluwalia, R. S., Grover, S. (2006). *Guidelines for Safe Dismantling of Obsolete Vessels in South Asia*. Invited paper at the International Conference on Dismantling of Obsolete Vessels, Glasgow, UK

Ahluwalia, R. S., Govindarajulu, S. (2005). A Software Tool for Disposal of Obsolete Vessels. *Journal of Ship Production*, Vol. 21, Num.1, pp 1-7

Ahluwalia, R. S., Sibal, P., Govindarajulu, S (2003). *Database for dismantling of obsolete vessels*. Intelligent Systems in Design and Manufacturing V, SPIE's International Photonics East Symposium, Providence, RI, October.

Artigues, C., Roel Leus, Fabrice Talla Nobibon (2013). Robust optimization for resource-constrained project scheduling with uncertain activity durations. *Flexible Services and Manufacturing Journal* June 2013, Vol. 25, Issue 1-2, pp 175-205

Ballard, G. (2000), *The Last Planner™ System of Production Control*. Unpublished PhD Thesis, School of Civil Engineering, The University of Birmingham.

Chabane, H. (2004), xa.yimg.com/kq/groups/24634788/1393872093/name/Art111.pdf

Charris, E., Carlos D. Paternina–Arboleda (2013). Simulation model of the supply chain on a naval shipyard. International *Journal of Industrial and Systems Engineering*. Vol. 13, Issue 3, 280-290, 2013-01-01, 10.1504/IJISE.2013.052277

Choo, H. (2003). *Distributed Planning and Coordination to Support Lean Construction*. Unpublished PhD Thesis, School of Civil Engineering, The University of California, Berkeley.

Chryssolouris, G. (2005). Manufacturing Systems: Theory and Practice, 2nd Edition New York, Springer-Verlag, 2005.

Chryssolouris (1), G., K. Dicke, M. Lee (1992). On the resources allocation problem. *International Journal of Production Research* 30 (12) (1992) 2773–2795.

Chryssolouris (2), G., J. Pierce, K. Dicke (1992). A decision-making approach to the operation of flexible manufacturing systems. , *International Journal of Flexible Manufacturing Systems*. 4 (3–4) (1992) 309–330.

Chryssolouris, G., M. Lee, K. Dicke, (1991). An approach to short interval scheduling for discrete parts manufacturing. *International Journal of Computer Integrated Manufacturing*. 4 (3) (1991) 157–168.

Chryssolouris, G., J. Pierce, K. Dicke (1991). An approach for allocating manufacturing resources to production tasks. *Journal of Manufacturing Systems*. 10 (5) (1991)368–382.

Chryssolouris, G. (1999). *A Planning and Control Method for Shipyard Processes: A Ship-repair Yard Case Study*. 10th International Conference on Computer Applications in Shipbuilding. ICCAS 99.

Chryssolouris, G., Makris, S., Xanthakis, V., &Mourtzis, D. (2004). Towards the Internet-based supply chain management for the ship repair industry. *Journal of Computer Integrated Manufacturing*. International 17(1), 45-57.

Costa, R., Eduardo G.M. Jardim (1998). Total punctuality approach for the jobbing industry. *International Journal of Operations & Production Management.* Vol. 18 Iss: 3, pp.260 – 270

Costa, R., Hill, J., Jardim, E. (1992). *Strategic management and shop-floor control in jobbing industry*. The British Production and Inventory Control Society. Vol. 18, N.2, pp.35-38, UK

De Boer, R. (1998). *Resource-Constrained Multi-Project Management - A Hierarchical Decision Support System*. Ph. D. thesis, University Of Twente, The Netherlands

De Boer, R., J.M.J. Schutten, W.H.M. Zijm (1997). *A Decision Support System for Ship Maintenance Capacity Planning*. CIRP Annals - Manufacturing Technology. Vol. 46, Issue 1, pp. 391-396, ISSN 0007-8506

Dlugokecki, V., Fanguy, D., Hepinstall, L., Tilstorm, D. (2010). Transforming the Ship Building and Ship Repair Project Environment. *Journal of Ship Production and Design.* vol. 26, num. 4, pp 265-272

Feng, W. (1), Li Zheng, Jingshan Li (2012). *The robustness of scheduling policies in multi-product manufacturing systems with sequence-dependent setup times and finite buffers*. Robotics and Automation (ICRA), 2012 IEEE International Conference on, pp.5074-5079

Feng, W.(2), Li Zheng, Jingshan Li (2012). Scheduling policies in multi-product manufacturing systems with sequence-dependent setup times and finite buffers. *International Journal of Production Research.* 50:24, 7479-7492

Framinan, J., and R. Ruiz. (2010). Architecture of Manufacturing Scheduling Systems: Literature Review and an Integrated Proposal. *European Journal of Operational Research*. 205: 237–246

Framinan, J., and R. Ruiz (2012). Guidelines for the Deployment and Implementation of Manufacturing Scheduling Systems. *International Journal of Production Research*. 50 (7): 1799–1812

Leus, R, Artigues, C.; Nobibon, F.T. (2011). *Robust optimization for resource-constrained project scheduling with uncertain activity durations*. IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). vol., no., pp.101,105, Dec. 6-9, 2011

MARAD,(2013), http://www.marad.dot.gov/documents/MARAD_Econ_Study_Final_Report_ 2013.pdf

Mello, M., J. O. Strandhagen (2011). Supply chain management in the shipbuilding industry: challenges and perspectives. *Journal of Engineering for the Maritime Environment*. 225:261-270, June 24, 2011

Moghaddam, K., John S. Usher (2011). *Preventive maintenance and replacement scheduling for repairable and maintainable systems using dynamic programming*. Computers & Industrial Engineering. Volume 60, Issue 4, May 2011, Pages 654-665, ISSN 0360-8352

Mourtzis, D. (2005). An integrated system for managing ship repair operations. *International Journal of Computer Integrated Manufacturing*. 18:8, 721-733

Papakostas, N., Papachatzakis, P., Xanthakis, V., Mourtzis, D., Chryssolouris, G. (2010). Decision Support Systems. "An approach to operational aircraft maintenance planning. *International Journal of Computer Integrated Manufacturing* Volume 48, Issue 4, March 2010, Pages 604-612, ISSN 0167-9236

Pinedo, M.L. (2012). Scheduling: Theory, Algorithms, and Systems. 4th ed. Springer; 2012-01-01

Pinha, D., Ahluwalia, R. S. (2013). *Decision Support System for the Ship Repair Industry*. SISE's 2nd Annual World Conference, Las Vegas, NV, USA, November 2013

Pinha, D., De Queiroz, M.H., Cury, J. E R. (2011). *Optimal scheduling of a repair shipyard based on Supervisory Control Theory*. Proceedings of the IEEE Conference on Automation Science and Engineering (CASE) 2011, pp.39-44, August 24-27, 2011

Thorpe, A., Bartlett, P. (2013). Buoyant floating energy sector promises rich pickings. *Special Offshore Supplement to Ship and offshore journal (SORJ)*. Volume 11 Issue 2, pp. 4. 2013

Van Dijk, R. (2002). http://alexandria.tue.nl/repository/books/587366.pdf

Wullink, G. (2005). *Resource Loading Under Uncertainty*", Beta Research School for Operations Management and Logistics. PhD Thesis. The University of Twente, The Netherlands

Wullink, G., Hans, E., Gademann, A., van Harten, A. (2004). Scenario based approach for Flexible Resource Loading under Uncertainty. *International Journal of Production Research*. 42 (24), 5079-5098

Yamashita, D., Amaral Armentano Vinícius, and Manuel Laguna (2007). Robust Optimization Models for Project Scheduling with Resource Availability Cost. *Journal of Scheduling*. 10.1 2007

Zhou, S., Ying Feng Zheng, Zhang Jiang, Meng Qiang Duan (2013). *Research of Scheduling Management in Warship Scheduled Repair Project*. Applied Mechanics and Materials. 409-410, 1564. 2013

Notations

Symbols	Description
NO	Number of Orders
i	Index of orders, i = 1 to NO
NT_i	Number of Tasks for order i
j	Tasks index, j = 1 to NT_i
THO	Committed Time Horizon
NPO	Number of Prospective Orders
p	Index of prospective orders, p = 1 to NPO
NTP_p	Number of Tasks for Prospective order p
k	Index of tasks for prospective orders, k = 1 to NTP_p
THPO	Time Horizon for Prospective Orders
R	Resources capable to performing task j or perspective task k
r	Index of resource R
t	Date/time value
$CD_{r,t}$	Current Demand for resource r to fulfill all orders by time t
c_{ijrt}	Committed loading for order i, task j, resource r up to time t
$PD_{r,t}$	Prospective Demand for a resource r during time t
TPD_r	Total Prospective Demand for a resource r up to THPO
pd_{pkrt}	Prospective demand of an order p, task k, requiring resource r, during time t
$AC_{r,t}$	Available Capacity of resource r during time t
c_{rt}	Regular capacity of resource r up to time t
o_{rt}	Overtime capacity of resources r up to time t