Development of a Theory of Constraints Based Scheduling System for Ship Piping Production

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Abstract: Manufacturing of ship piping system is one of the major production activities in shipbuilding. The schedule of pipe production has an important impact on master schedule of shipbuilding. In this research, the theory of constraints (TOC) concept is introduced to solve the scheduling problems of piping factory, and an intelligent scheduling system is developed. The system integrates a product model, an operation model, a factory model and a knowledge database of piping production and can make the process planning and production scheduling automatically. In the paper, details of above points are discussed. Moreover, an application of the system in a piping factory, which achieves a higher level of performance as measured by tardiness, lead time and inventory, is demonstrated at the end of the paper.

Key words: piping factory, scheduling system, theory of constraints (TOC)

1 Introduction

Shipbuilding is a large scale manufacturing project. During the construction stage, the hull is assembled and painted, as well, the equipments, pipes, electrical cables, and some other components are required to be installed. To the master plan of a ship's construction, the production of these outfitting components can be seen as the supporting industries of shipbuilding, and is then very important. In this research, the scheduling management of piping production is discussed.

Piping systems are used extensively throughout a ship for conveying fluids. Piping production takes place in pipe factory—a kind of job shop. Due to the large number and great variety of ordered piping products from shipyard, it is a complex work to make an effective scheduling for the production. Moreover, piping factories are facing lack of experienced engineers, which further brings a challenge of increasing throughput and efficiency by scientifically managing the production process. Therefore, human managers of the factories are greatly overburdened by the complexity of this scheduling task.

On the other hand, theory of constraints (TOC) is applied to approach this problem. The TOC concept developed by Goldratt involves an integrated treatment of many concepts, such as goals and necessary conditions, performance measures, scheduling, process improvement, buffer inventories, marketing and accounting[1]. In recent years, both trade and academic journals have reported cases in which companies have achieved operational excellence, in terms of increased throughput and reduced inventory and operating expenses.

Obviously, TOC has emerged as an effective management philosophy that has successfully tackled the scheduling problems in mass manufacturing plants[2]. However, in case of piping factory which is of high complexity in production, implementation of TOC is obstructed due to lack of a suitable computerized tool. To overcome the difficulty, this research develops an integrated production scheduling system for piping factory based on the TOC concept. At first, process planning is automatically executed based on the product information by using the factory model and a knowledge database. Next, the facility and scheduling of each operation are decided based on the related knowledge including the TOC concept. Moreover, scheduling results of the system and some widely using methods are compared. As a result, proposed system achieves a higher level of performance as measured by mean lead time, mean tardiness and inventory level in the application.

2 Theory of Constraints

The TOC concept is a manufacturing strategy to improve the performance of an organization by maximizing throughput while reducing inventory and operating cost at the same time. This leads to simultaneous
increase in net profit, return-on-investment, and cash flow. Mabin and Balderstone[3], in their meta-analysis of seventy-eight published case studies, reported that implementing TOC resulted in mean reduction of lead time of 66%, mean improvement in due date performance of 60% and mean reduction in inventory levels of 50%.

Differing from the popular critical path method (CPM) which does not consider the resource constraints, one key idea of TOC is that the production system’s constraints determine the system’s throughput and should be the focus of management attention. A constraint is defined as a unit in the manufacturing process that holds down the amount of products that a factory can produce. A constraint may include a machine or an operator whose capacity limits the throughput of the whole production process. Concentrating on the exploitation of constraints, TOC concept provides a continuous improvement and the concept consists of five focus steps[4].

(1) Identifying the constraint. The constraints may be inside (e.g. capacity, policy) or outside (e.g. market, supply) the system. In case all constraints are not broken easily, the managers should proceed to the next step.

(2) Exploiting the constraint. There are usually a variety of ways to do this. It must assure that decisions maximize using the constraint in terms of the goal.

(3) Subordinating to the constraint. It is the most important step of on-going improvement process. Subordination redefines the objective of every process in the system by assuming that each process is aiming to accomplish a mission independently and thus attempts to achieve the overall goal of the manufacturing unit. However, sometimes there may be conflicts of priorities between two processes, such as competition for the same resources. It is possible that after subordinate step, system constraints may be broken, but some other units transform to become bottleneck elements. In such a situation, the whole process of five focusing steps starts again by redefining the system constraints.

(4) Elevating the constraint. Sometimes after executing Step (3), some original constraints remain as system constraints, and then it is assumed that for the given optimal solution is achieved and it is not possible for the system to perform better without supplementary management actions.

(5) Returning to Step (1). Note that no inertia become constrain.

3 Scheduling of Piping Production

3.1 Overview of Piping Production

Piping factory is a typical make-to-order job shop which gears to satisfy customer-requirements on receiving an order from shipyards[5]. According to piping factories and shipyards, the production environments including technical conditions, management levels, and so on cannot be the same as well.

(1) Product. The majority of piping products are jointed by butt-welding, with flange connections or other mechanical components, such as elbow, reducer, sleeve and tee. Flow rate, viscosity and pressure of fluid being carried determine a pipe’s material and diameter. Technical requirements may make a great variety of piping products.

(2) Order and lead time. As to the piping factory, the shipyard’s weekly demand consists of hundreds of products required to be processed in a lead time of 3—4 weeks. Both graphic and data format documents to describe the ordered products are available. The due dates of products are also mentioned in the order.

(3) Facilities. In a piping product’s manufacturing process, a set of operations, i.e., cutting, bending, assembling and welding are carried out by different types of facilities. Certain type of facilities can be further characterized by their allowable diameter of pipes which can be processed. Besides, material, length, and some other limitations of processed pipes also should be inspected before being operated. According to the varied properties of processed pipes, operation time is different but normally in a short period. Setup time of facilities incurs when a facility switches to processing a pipe with different size. The pipes wait in a queue before the facility becomes available.

(4) Workflow. The workflow is a depiction of a sequence of operations and determined by experienced engineers. Considering the related practical knowledge and the constraints of required facilities, the workflows are varied a lot between each other. Taking a product with a workflow of cutting-assembling-welding-bend for example, in situations where the bending operation cannot be carried out because the work piece might not be handled by the bending facility after assembling. Therefore the bending operation has to be shifted before assembling, and the workflow is modified as cutting-bend-assembling-welding.

(5) Process planning and scheduling. In piping production, process planning concerns the generation of product required operations, the allocation of resources to specific operations and the determination of workflow. Next, to meet the ordered due date of the product, the operations are scheduled under a timely plan. In the scheduling process, some widely using methods i.e. the earliest due date (EDD) and the shortest processing time (SPT) are applied.

3.2 Scheduling Problem

The scheduling work of piping production is greatly complicated by the large quantity and the large variety of ordered products which are processed in short lead time. Furthermore, the scheduling methods being applied in the production pay too much focus on the