The impact of powers-of-two based schedule on the minimization of inventory costs in a multi product manufacturing environment

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Abstract

This paper discusses about the scheduling problem of a multi product manufacturing industry. Often there has been a problem of applying optimization algorithms to solve the makespan minimization criterion of a job shop due to its inherent NP-hard nature. It is therefore unrealistic to try obtaining a solution through a commercial solver in polynomial time. In this context, we propose a computationally effective heuristic, which is based on the powers-of-two policy in inventory, for solving the minimum makespan problem of job shop scheduling. The research discussed in the current paper is a real time scheduling problem faced by a large scale and complex turbine manufacturing job shop. It is worth noting that by integrating the material requirements planning (MRP) with the feasible schedule obtained, this policy also proves to be useful in minimizing the inventory costs.

Keywords

Powers-of- two, job shop schedule, inventory, material requirements planning, lot size.

Introduction

The problem of scheduling job shops is widely encountered in many manufacturing industries and still finding methods for improvement. Generating a good job shop schedule for a multi-product manufacturing industry in a reasonable time remains a challenging problem, because of the Non-deterministic-Polynomial (NP) hard nature of job scheduling and its inherent computational complexity. In this paper we consider the makespan minimization problem of a turbine manufacturing industry based in India. The production planning and control (PPC) department of the industry has to schedule the jobs, on the available special purpose machines (SPMs), respecting the capacity constraints and most importantly the priority of work orders. We propose a powers-of-two based heuristic for solving job shop scheduling problem. This paper is mainly intended to investigate the impact of powers-of-two based schedule on the minimization of inventory costs in a turbine manufacturing industry.

This paper proposes a different approach in the hierarchical flow of various planning activities. It follows a schedule based planning approach (SBPA) in which, it will generate a near optimal schedule first by considering the capacity requirements and their availability. The production schedule thus generated provides a basis for performing a time-phased materials requirements planning. This change in the hierarchical flow of planning is possible because of the nature of the problem under consideration. Though the turbine manufacturing industry is considered as job shop based on the distinct operation sequences required by various parts of a turbine, the customer orders received by it almost consist similar material and processing requirements. When a new work order is received, the route sheet and bill of material of it are generated by retrieving the data pertaining to an equivalent work order, which is stored in a master database. The efficacy of the powers-of-two scheduling approach is tested on MRP systems by comparing the inventory carrying costs and resource allocation to those obtained by using a priority based scheduling approach. In general, it is concluded that the proposed model provides improved schedules with considerable reductions in inventory carrying costs.

The rest of this paper is organized as follows: We present the literature survey in Section 2, followed by the problem formulation in Section 3. In section 4 we present our powers-of-two heuristic for solving complex job shop scheduling problem. The integration aspects of material and capacity requirement planning and schedule based planning approach is discussed in section 5. We investigate the impact of powers-of-two schedule on inventory costs in section6. Finally the conclusions of the study are presented in section 7.

Literature Survey

In this section, we survey the relevant literature. Bertsimas et al. (2003), design an algorithm for the high-multiplicity job-shop scheduling problem. They consider the objective of minimizing the total holding cost by employing a round off to optimal solution technique via a fluid relaxation. In fluid relaxation, the authors assume replacement of discrete jobs with an equivalent flow of continuous fluid. Their algorithm solves the fluid relaxation optimally and then aims to keep the schedule in the discrete network close to the schedule given by the fluid relaxation. Luh et al. (1999) presented an approach for job-shop scheduling in an uncertain environment wherein there are, uncertain arrivals, processing times, due dates and part priorities. The authors use a separable problem formulation that balances modeling accuracy and solution method. A grid based scheduling system for solving large scale problems faced by a virtual manufacturing enterprise was proposed by (Hong, 2006). Thiagarajan and Rajendran, (2005) propose dispatching rules for dynamic job shop scheduling. They consider objective of minimizing the weighted earliness and weighted tardiness. Authors verify the effectiveness of dispatching rules via simulation. Tavakkoli and Mehr (2005) use simulation for job-shop scheduling problem. They consider the objective of minimizing the make-span.

An evolutionary algorithm based approach for solving the job shop scheduling problem was presented by (Mesghouni et al. 2004). The authors address the problem of minimizing the makespan in a flexible job-shop environment. Esra (2002) developed a model to obtain realistic and easy-to schedule lot-sizes in a multi-product, multi-stage manufacturing environment. The study focuses on a specific industry – paint industry in order to represent the characteristics in more detail. According to Muckstadt and Roundy (1993), the reorder interval T must be a power-of-two (i.e., 1, 2, 4, 8, ..., 2k, ..., where k is a nonnegative integer) times the base planning period, i.e. $T = 2^k T_L, k \in \{0,1,...\}$. By restricting to a policy of this form, an average annual cost of a solution exceeds the optimal cost by no more than about 6%. Federgruen and Zheng (1992) consider set-up to be a monotonic sub modular function of the set of retailers served. Inventory costs just at retailers. Depending on whether the base planning period is fixed or variable, the optimal power-of-two policy comes within 6% or 2% of an easily computable lower bound for the minimum cost value. As a by-product they provide an allocation of the joint setup costs to each product.

Ashutosh (2000) discussed an important practical problem of planning the production of large assemblies employing an MRP-based system. The objective is to produce products on time, with minimal cycle time and low work-in-process costs. He has also demonstrated the workload smoothness calculations. Jiao (2000) proposes a data structure called a generic bill-of-materials-and-operations (BOMO), by unifying bill-of-materials (BOM) and routing data in to a single set in order to synchronize multiple perspectives on variety such as customer ordering, product engineering, and operations planning. An implementation of the proposed generic BOMO methodology in customized souvenir clock manufacturing is also reported.

The far-reaching consequences of unifying bills of material and routings on the basic functions of production planning and control were examined by Tatsiopoulos (1996). Enns (2005) compares Lot-For-Lot (LFL) and Period Order Quantity (POQ) policies with a Fixed Order Quantity (FOQ) policy, within which lot sizes are based on minimizing, estimated lot flow times at capacity-constrained machines. Simulation is used to study a small production and distribution network using time-phased planning. According to Walter (2002), the material requirements planning can be done more effectively in a job shop environment using a resource constrained project scheduling model. The proposed model augments MRP models by incorporating capacity constraints and using variable lead time lengths. The efficacy of this approach is tested on MRP systems by comparing the inventory carrying costs and resource allocation of the solutions obtained by the proposed model to those obtained by using a traditional MRP model.

Gursel (1993) reports the results found in regard in the performance of three scheduling policies in a material requirements planning environment. The policies included in the study are shortest processing time, earliest due date and Moore's algorithm. Each work center is assumed to have only one machine and as a result this study is limited to the single machine scheduling applications. A new methodology for dimensioning an overall buffer against uncertainty in demand in MRP environments was provided by (Caridi and Cigolini, 2000). For this purpose, a set of recommended guidelines is reported to dimension and position safety and/or strategic stocks within products bills of materials and manufacturing pipelines.

Callarman and Hamrin (1983) compare dynamic rules to determine the production lot sizes for articles with independent demand in a single-stage MRP system. The authors study three methods: EOQ, Wagner–Whitin, and PPB. The authors conclude that the PPB procedure is the best for lot sizing in a single-stage inventory system with uncertainty in demand. The authors modelled the uncertainty in demand using probability distributions. An integrated approach for material planning and finite operation scheduling (IMPOS) was presented by (Fallah, 2002). The approach assumes the existence of a system that provides a relative priority measure for customer orders, based on a predetermined set of factors including – but not limited to – due dates. The IMPOS approach attempts to reduce production lead times during its finite scheduling procedure through analysis of the details of each operation in conjunction with order associated operations and the ordering policy applied.

Problem Description

The problem is discussed from the perspective of a multi product manufacturing industry under investigation. The industry considered for the study is a world-class leader in turbine manufacturing situated in India. The production planning and control (PPC) department of industry has to schedule number of jobs, on the available special purpose machines (SPMs), respecting the capacity constraints, tooling availability and most importantly the priority of work orders. The industry manufactures several types of turbines (steam, gas), besides compressors and generators. To summarize, the industry is a complex job-shop, which is capable of manufacturing host of products with a wide scope in variety.

From the time a customer places an order for a particular product, the order is uniquely identified by a Work Order Number (WONO). Each Work Order (i.e. Product) consists of several sub-assemblies and they are identified by a unique number known as Product Group Main Assembly (PGMA). Further each product group consists of individual parts identified by PARTNO and the operation sequence of each part is identified by Operation Number (OPNO). The industry may have thousands of parts to be processed on various machines in a given time horizon and a part may ***recirculate*** a machine more than once.

The complexity and magnitude of the scheduling problem can be better understood by considering a product like steam turbine. The steam turbine is a heavy machine consisting of approximately 800 components, which may be classified into, major, sub-major, and minor components. Out of all these components there are about 15 to 30 critical components that are manufactured in the heavy machine shop. The processing sequences of major parts of these turbines are similar to some extent. However, depending on the engineering requirements of a typical customer this would change. The industry maintains the history of process planning of all the work orders that were processed on the shop floor. A new work order details are appended into a large-scale manufacturing enterprise system. The process plan of work order is developed by retrieving the information from an equivalent work order from the enterprise. The complexity of generating a typical process plan would vary greatly. For work orders, which are exactly similar in terms of routing and processing requirements, this task will involve a copy, but if the new work order has a different requirement then it takes non-trivial engineering effort and hence increased time in process planning.

The authors have proposed a priority based heuristic and its implications in a turbine manufacturing industry in their earlier work (Sandeep, Mahesh and C S P Rao, 2009).

Powers-of-Two Based Scheduling

The crux of this heuristic is to accommodate the manufacturer's/planner's intelligence blended into the generalized job-shop make-span minimization framework for achieving good results. It is well known that powers-of-two concept has been widely useful in the inventory control literature (Muckstadt, J.A., Roundy, 1993). The concept of powers-of-two in inventory control can be mapped with job-shop scheduling application. The mapping in this case is a cost to time map. The inventory control setup deals with cost structure while in the job-shop scheduling the key variable is time/make-span. The planner's are given arbitrary release dates for work-orders (hence the underlying jobs) from the planning department. Planner's take this as input and try to match it to a nearest powers-of-two release date.

To get a detailed overview of powers-of-two based scheduling heuristic and the establishment of bounds for the makespan, interested readers are referred to our earlier paper (Mahesh V, Sandeep Dulluri, A.C Reddy and C S P Rao, 2008).

We apply first the priority heuristic to obtain an initial solution. The make span obtained by the priority heuristic for 10 work orders of the problem under consideration is reported in Table 1. The release dates of work orders are arbitrary as given by the planning department. While scheduling these work orders on the available machines, if two jobs are waiting to be processed on the same machine, the job with the higher priority is given preference and will be processed first. The job with the lower priority is kept waiting till the processing of higher priority job finishes. However the size of the problem that is taken for experimentation using powers-of-two is as follows: 10 work orders – with each work order consisting of about 15 parts. Each part on an average undergoes 30 operations. There are 20 work centers and considering the parallel machines, the total number of machines amount to 82.

S.No	Work order No	Initial Priority	Release Date (days)	Makespan (days)
1	WONO 1	1	1	32
2	WONO 2	2	19	55
3	WONO 3	6	28	73
4	WONO 4	3	45	100
5	WONO 5	5	27	128
6	WONO 6	4	49	125
7	WONO 7	7	56	155
8	WONO 8	8	70	180
9	WONO 9	9	82	205
10	WONO 10	10	110	228

Table 1: Makespan of Work orders with random release time

We report, in Table 2, the nearest powers-of-two release dates as well as the makespan results of 10 work orders. The partial summation of the nearest powers-of-two is taken as release date so that it approaches nearer to the arbitrary value considered in Table 1. We see that the maximum/minimum adjustment to the release date will not exceed half the nearest powers-of-two. It is observed that the net saving of makespan is about 133 days compared to the random release date.

S.No	Work order No	Initial Priority	Release Date (days)	Makespan (days)
1	1	1	1	32
2	2	2	16	49
3	3	6	24	69
4	4	3	48	101
5	5	5	24	120
6	6	4	48	126
7	7	7	48	152
8	8	8	68	178

9	9	9	80	203
10	10	10	96	226

Table 2: Makespan of work orders with nearest powers-of-two release time

Integrated Material and Capacity Planning

The main function of MRP is to determine the materials required for production by quantity and time. A major criticism to the MRP II approach concerns the concept of successive material and capacity requirement planning. The results of material requirements planning stage (MRP) are the input to the following capacity requirements planning (CRP) and feedback can be achieved only with difficulty. To overcome this, an integrated approach of simultaneous material and capacity planning is required.

An early effort is reported by (Hastings and Will, 1982) for an integrated approach to production scheduling and material requirement planning which simultaneously consider the feasible production schedule and material requirement plan. This paper also proposes bill of manufacture (BOMfr) structure for achieving a unified material and capacity planning. From the BOMfr, a finite capacity production schedule can be generated. The quantity of material required by each operation is calculated from the job data derived from the BOMfr and the date required is the planned feasible start time of that operation in the production schedule. Aggregated gross material requirement reports for a given time horizon and for a certain number of work orders can be generated for each type of material based on the production schedule. Though a wealth of literature can be found in the areas of scheduling and MRP, there is sparse literature relating MRP to job shop scheduling problems. Several heuristics were available to deal Job shop scheduling and shop floor inventory management problems separately. They may not be applicable directly or insufficient to solve scheduling problems of a multi product manufacturing industry.

Schedule Based Planning Approach (SBPA)

The schedule based planning approach (SBPA) coordinates all the resources and materials required for manufacturing products to meet demand from actual customer orders. In SBPA approach, production data is maintained by the BOMfr structure, which integrates the BOM and routing data. Production jobs are identified from the BOMfr and they are scheduled on the finite capacity available. The scheduling procedure generates a realistic, feasible production schedule, giving the planned start and finish times of each production operation at the corresponding work place/work center.

The production schedule thus obtained forms a basis for performing the demand and supply analysis of the items for time-phased materials planning. From the detailed production scheduled obtained for various work orders, the requirement of materials for each operation is identified by quantity and time. This results in an integrated production and material requirements plan. By further incorporating current status of stock on hand, work in progress (WIP), customer orders, and purchase orders into the analysis; an item status report is generated (Yeh, 1995). Whenever the materials required for processing are not available as per the scheduled date then the re-scheduling is done as per the modified date on which the materials become available for processing.

In SBPA, the main function of MRP i.e., the determination of material required for production by quantity and time is carried out by a finite capacity scheduling procedure. The quantity of materials required by each operation is calculated from the job data created from the BOMfr, and the date required is the planned feasible start time of that operation in the production schedule. This constitutes an integrated production and material requirements plan, in which materials are associated with specific operations in the production schedule. Aggregated gross material requirements reports by day, week or month can be produced for each material required in the production schedule. The second phase of the material demand analysis involves creating a material status report that shows the status for any material involved in the production schedule. This is accomplished by relating the time-phased, operation-associated requirements of each item to the current stock on hand and purchase orders with due dates (Yeh, 1997).

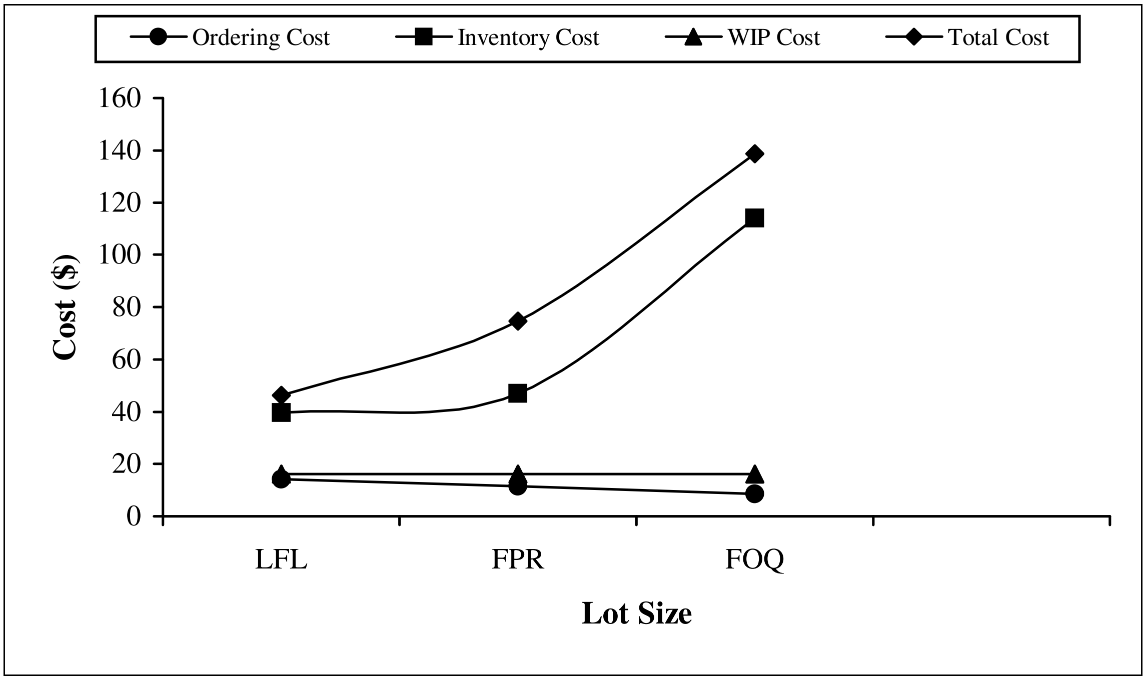
Table 3 shows the material data used in the calculation of inventory costs. The lead-time of various materials provided in the Table is used to find the planned order release.

Name of material	**Lead time (Weeks)**	**Ordering Cost / Order ($)**	**Holding Cost / Unit Weight ($)**
Structural Steel	1	1.78	0.40
Alloy Steel Castings	2	3.00	0.70
Alloy Steel Forgings	2	2.38	0.60
Bronze Lining	1	1.42	0.20
Carbon Steel Castings	1	2.85	0.36
Cast Carbon Steel	1	2.85	0.30
Cast Iron	2	1.20	0.36
Chromium Nickel Steel	1	2.00	0.24
Grey Cast Iron	2	2.14	0.30
Nickel Steel	1	1.67	0.24

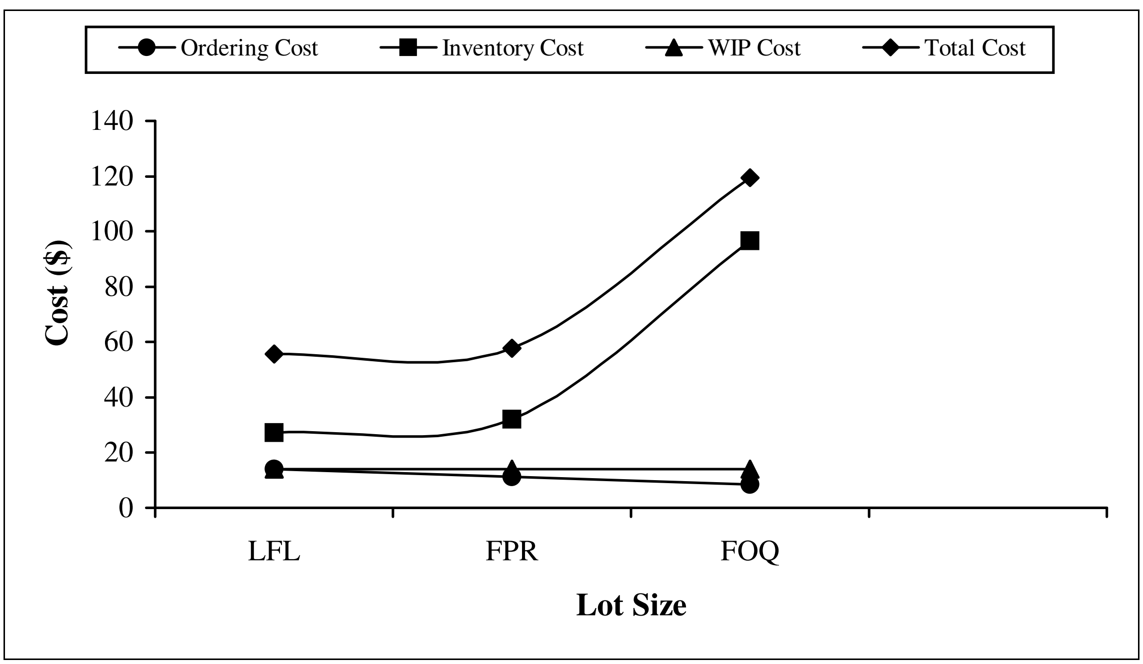
Table 3: Material data used in the calculation of inventory costs

Impact of Powers-of-Two Based Schedule on Inventory Costs

Once the finite capacity schedule is generated, the quantity of material required by each operation is calculated from the job data derived from the BOMfr and the date on which the material required is obtained from the schedule. Section 4 has given a detailed discussion on powers-of-two policy applications in job shop scheduling. The schedule generated using Powers-of-two policy proves to be minimizing the makespan. This in-turn reduces the work-in-process inventory and also the cost associated with WIP. Figures 1and 2 below illustrates the comparision of ordering cost, inventory cost, WIP cost and total costs of different materials by considering schedule input with random dates input and powers-of-two dates input. It is observed that in all the three lot sizing techniques implemented in this paper, the inventory costs are minimal when the schedule is generated on the basis of powers-of-two policy.

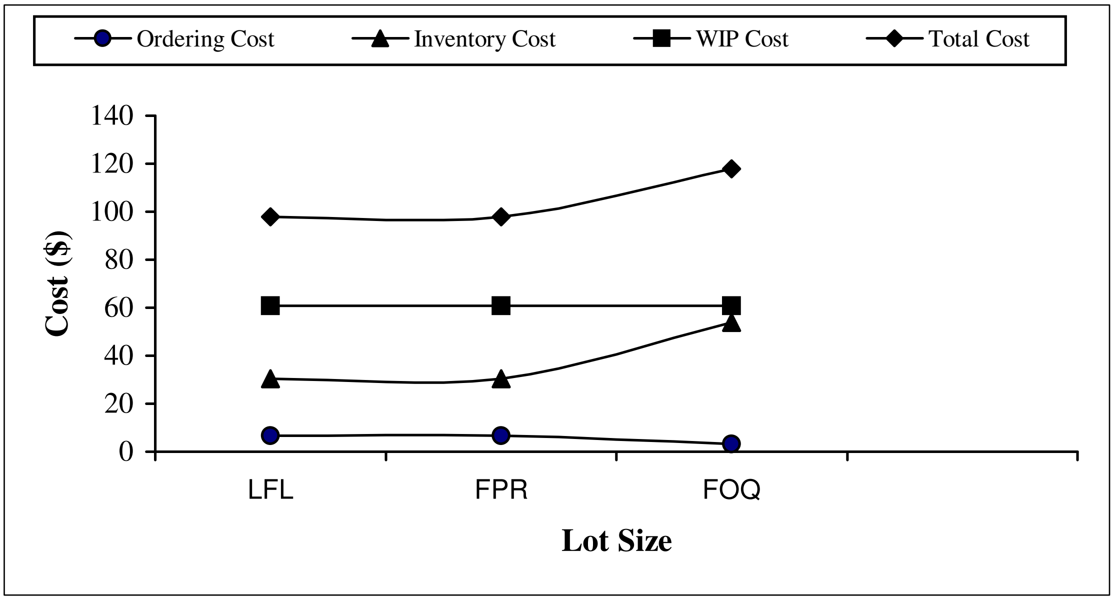


(a) Schedule input with random dates

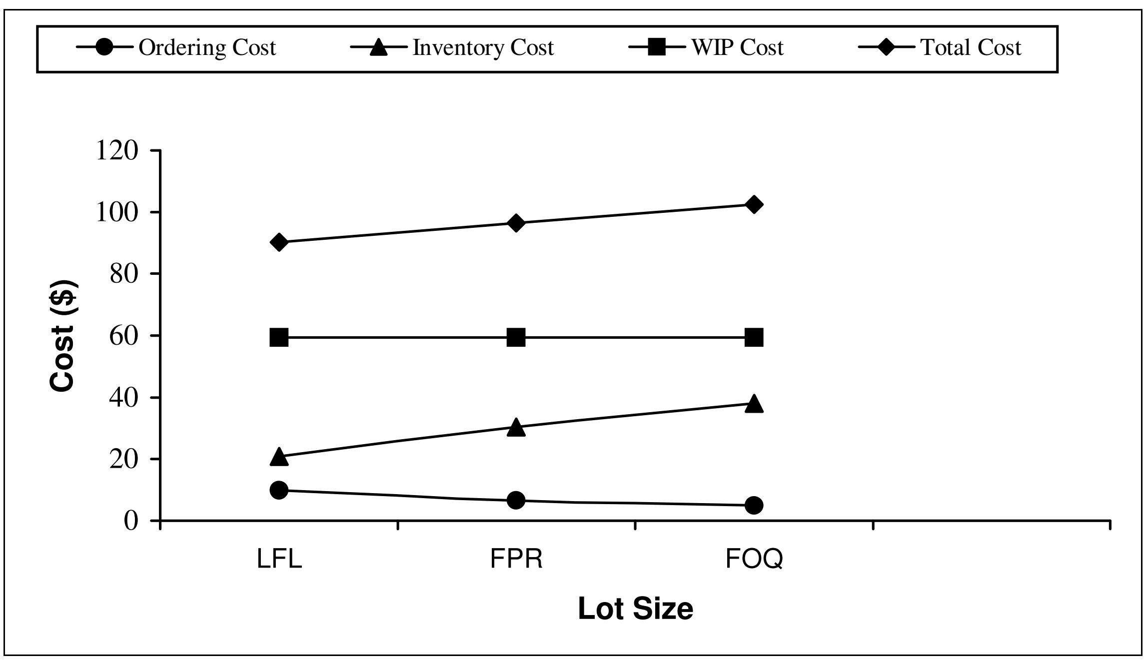


(b) Schedule input with powers-of-two dates

Figure 1: Cost comparison for various lot sizing techniques using schedule input with random dates Vs schedule input with powers-of-two start dates (for Cast Carbon Steel material)



(a) Schedule input with random dates



(b) Schedule input with powers-of-two dates

Figure 2: Cost comparison for various lot sizing techniques using schedule input with random dates Vs schedule input with powers-of-two start dates (for Nickel Steel material)

Conclusions

In this paper, we have discussed a problem of integrated production planning faced by a turbine manufacturing job-shop. In particular, we focussed on the integration of machine scheduling and inventory planning. We proposed a heuristic for machine scheduling which is based on the concept of powers-of-two. The powers-of-two based schedule has shown much improvement in the make span minimization compared to the priority based schedule which is currently adopted in the industry. The schedule based planning approach (SBPA) presented in this paper produce a near optimal schedule, respecting the capacity constraints and considering the job release dates as nearest powers-of-two. The production schedule thus generated provides a basis for generating a time phased material requirements planning.

As a by-product of this research, we had an interesting observation that powers-of-two schedule, when given as input to the material requirements planning resulted in minimizing the inventory costs.

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Risk Visualization: A Mechanism for Supporting Unstructured Decision Making Processes

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Abstract

The premise of this paper is that risk visualization has the potential to reduce the seemingly irrational behavior of decision makers. In this context, we present a model that enhances our understanding of visualization and how it can be used to support risk based decision making. The contribution of our research stems from the fact that decision making scenarios in business are characterized by uncertainty and a lack of structure. The complexity inherent in such scenarios is manifested in the form of unavailability of information, too many alternatives, inability to quantify alternatives, or lack of knowledge of the payoff matrix. This is particularly prevalent in domains such as investment decision making. Rational decision making in such domains requires a careful assessment of the risk reward payoff matrix. However, individuals cope with such uncertainty by resorting to a variety of heuristics. Prior decision support models have been unsuccessful in dealing with complexity and nuances that have come to typify such heuristic based decision making.

Keywords

R*isk visualization, investment decisions, risk propensity, risk perception, risk estimation.*

1. Introduction

In this paper, we introduce the concept of risk visualization for effective and rational decision making. Risk visualization is defined as a process that helps decision makers assess and evaluate risks of possible decision choices. Risk visualization has implications to improve decision making in unstructured environments and to reduce irrational behavior of decision makers. The ability to visualize risk may be