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Implementation of an online scheduling support system in a high mix manufacturing firm

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Abstract

Scheduling is an important decision making processes in any manufacturing industry. One of the key objectives of scheduling is minimizing the makespan. Generating the best job shop schedule with the makespan criterion for a multi-product manufacturing industry in a reasonable time remains a challenging task, due to its NP hard nature. In this context, this paper discusses the implementation of an online scheduling support system for a high mix manufacturing firm. The firm is a world-class leader in turbine manufacturing, based in India. The production planning and control (PPC) department of firm has to schedule the jobs, on the available special purpose machines (SPMs), respecting the capacity constraints and most importantly the priority of work orders. The system is developed in two phases. The first phase involves the development of a scheduling support system. A priority based heuristic for minimizing the makespan is presented. The heuristic considers a host of real world issues, like resource breakdown, utilization, recirculation of the jobs on the machines etc. The crux of this paper is to present an approach to smoothen the work loads viz., under loads and over loads, that occur on various machines due to the lack of integration between capacity planning and generated schedule. The second phase involves integrating it with World Wide Web (WWW) which allows the decision makers with the flexibility of distributed decision making.

Keywords: Job shop scheduling, makespan, capacity planning, World Wide Web (WWW)

1. Introduction

This paper is intended to discuss a job shop scheduling problem from the perspective of a high mix manufacturing firm under investigation. The firm is a world-class leader in turbine manufacturing, based in India. The production planning and control (PPC) department of firm has to schedule the jobs, on the available special purpose machines (SPMs), respecting the capacity constraints and most importantly the priority of work orders. From the time a customer places an order for a particular turbine the order is uniquely identified and all the parts regarding the turbine (product) are also identified. The firm manufactures several types of turbines (steam, gas), besides compressors and generators. To summarize, the firm is a complex job-shop, which is capable of manufacturing host of products with a wide scope in variety. A large variety of constraints and relaxations must be added to classical job shop scheduling problem (JSSP) in order to represent real production environments. The number and type of constraints depend on the environment under consideration. It is impractical to design a universal scheduling system that considers all the characteristics of every production environments.

Nevertheless, some constraints and alternatives have a high frequency of occurrence in real job shop environments. A scheduling system which models these commonly encountered characteristics would be able to solve the absolute majority of industrial job shop scheduling problems that rise in practice. This paper includes the following characteristics in a relevant subset of real constraints and alternatives for the above discussed problem:

- Jobs with different priorities
- Job priorities may vary with time. The basis for deciding the priority is the progressive payment of customer

- The sequence of operations for manufacturing a product is fixed.
- The part or job may visit the same machine several times i.e. the *recirculation* of jobs is allowed.
- The efficiencies of the work places may vary with time and there is a possibility of breakdown.
- Several sub-assembly levels, i.e., existence of a bill of material for each product (job)

The firm has number of plants located at various places in India and it has customers placed in different countries. The scheduling system is web enabled so that these geographically dispersed plants can be integrated through World Wide Web (WWW), which helps the managers in taking quick decisions and in satisfying the customer demands. The system is developed in two phases. The first phase involves the development of a scheduling support system and the second phase involves integrating it with World Wide Web (WWW).

Organization of this paper

This paper is organized as follows: In section 2, we present the literature survey that is relevant to the current problem we investigate. Section 3 deals with the traditional method of representing product and production data and the concept of bill of manufacture (BOMfr). This paper deals with the real time scheduling problem faced by a turbine manufacturing firm. In this regard, we present the formulation of the problem, notation and math framework in section 4. In section 5 we discuss our priority based heuristic for solving a complex large scale job shop scheduling problem with a near to optimal solution in a fully polynomial time. The results of job-shop scheduling with our proposed heuristic and allied comparisons with established algorithms in the literature are provided in section 5. This section also deals with workload smoothening via integration of scheduling with capacity requirement planning. Section 6 discusses the integration of the scheduling system with the web. Finally we present conclusions in section 7.

2. Relevant Literature

This research work integrates two strands of literature namely; job-shop scheduling and web integrated manufacturing/planning applications. We survey some relevant literature that is most relevant to our current work, and hence this survey is not exhaustive.

2.1 Job-shop Scheduling

Blum (2002) proposes an ant colony based meta-heuristic for group shop scheduling and presents a detailed overview of scheduling techniques available for group shop. Kumar and Rajotia (2006) discusses integrating the process planning and the job-shop scheduling problem. Our work shares some similarity with them, we provide a *math* framework supporting our work. A comprehensive overview on the job-shop scheduling problem (JSSP) is presented by Yamada and Nakano (1997). In particular they emphasize on the “disjunctive-graph" approach for solving the JSSP. The dispatching rules for dynamic job shop scheduling was proposed by Pezzella and Merelli (2000). They consider objective of minimizing the weighted earliness and weighted tardiness. Authors verify the effectiveness of dispatching rules via simulation. In the current work, we use a priority based heuristic framework blended with the dispatching rules (to resolve resource contention) for a real-time complex job-shop. Job insertion problem in multi-stage scheduling finds the feasible insertion of the additional job in to the schedule that minimizes the resulting makespan (Arjen et al., 2007). A computationally effective heuristic method for solving the minimum makespan problem of job shop scheduling was presented by Thiagarajan and Rajendran (2005). The local search method adapted by them is based on the tabu search technique guided by shifting bottleneck procedure. Chung et al.(2005) considers manufacturing industries where outsourcing of manufacturing operation is possible through subcontract. The problems in scheduling a set of jobs associated with random due dates on a single machine so as to minimize the expected maximum lateness in stochastic environment was considered by Xianyi and Xian (2007). The cyclic job shop scheduling problem with linear constraints was presented by Cavory et al.(2005). An algorithm for job-shop scheduling based on global equilibrium search techniques was also proposed by Cavory et al.(2005). However, the authors do not address the concept of “job clashes" encountered in job-shop; also they limit their algorithm to work with deterministic data.

Ye Li and Yan Chen (2010) proposed a new genetic algorithm for solving the agile job shop scheduling problem. They adopted two-row chromosome structure based on working procedure and machine distribution. Tamilarasi and Anantha kumar (2010) developed a new method for solving job-shop scheduling problem using hybrid Genetic Algorithm (GA) with Simulated Annealing (SA). This method introduces a reasonable combination of local search and global search for solving JSSP. However, the proposed method assumes that each operation of a job is to be completed on a single machine. D.Y. Sha and Cheng-Yu Hsu (2006) proposed a hybrid particle swarm optimization (PSO) for the job shop problem (JSP). The authors have modified the particle position based on preference list-based representation, particle movement based on swap operator, and particle velocity based on the tabu list concept in their algorithm. D.Y Sha and Hsing-Hung Lin (2010) have applied a particle swarm optimization (PSO) for an elaborate multi-objective job-shop scheduling problem. Due to the discrete solution spaces of scheduling optimization problems, the authors modified the particle position representation, particle movement, and particle velocity in their study.

2.2 Web based manufacturing applications

Huang and Mak (2001) in their paper focus on a number of major initiatives and projects recently completed or just launched on web-based product design and manufacture. Yang and Xue (2003) have given a comprehensive review of extant research on developing web-based manufacturing systems. The authors focused on key issues in developing web-based manufacturing systems, including collaboration among product development partners, data modeling, system architecture design, and security management. The functioning of a multiple criteria decision support web-based system for facilities management was presented by Edmundas et al.(2004). Jiang et al. (2007) presented an e-service-driven networked manufacturing model. This model is implemented using some key enabling techniques like e-formalizing bottom manufacturing resources; up-streaming manufacturing data and co-enterprises based on products to be manufactured. Mahesh et al. (2007) describe a framework for a web-based multi-agent system (WebMAS) to allow collaborative product development and production among geographically dispersed functional agents using digital information.

This work can be viewed as a logical extension of our previous work on job-shop scheduling (Krishna et al (2002) & Sandeep et al., 2008). We differ from the extant literature in the following way:

a) we model the re-circulation of jobs
b) we incorporate multiple jobs with parallel machines, and each job can have change in priorities at the run time.
c) we investigate the linkage between make-span and capacity utilization in complex job-shop environment.
d) Another significant contribution of our research work is web enabling the scheduling support system. This helps users of the different plants of the firm located at geographically dispersed places to operate the scheduling system using the features of World Wide Web (WWW).

3. Traditional method of representing product and production data

In case of MRP II, there is a long established tradition in separating the product structure in the form of the *bills of material (BOM)* and the process structure in the form of *routings*. These two groups of data items together with the work centers as capacity units form the traditional basic elements of the manufacturing process (Suwa and Sandoh, 2007).

A logical representation of product data and production information plays very important role in production planning and control for performing functions such as material requirements planning (MRP), capacity requirements planning (CRP), operation scheduling and shop floor control (Pardalos and Shylo, 2005).

Hence an effective production planning and control system requires combining the bill of material (BOM) and routing data to reflect the material flow through the production process. An integrated BOM and routing data model allows the flexibility in handling relationships between materials and operations to suit specific needs. It can also be used as a standard data resource for creating production jobs (Yeh , 1995) .

Product represented by a BOM can be used for describing an end product to state raw materials and intermediate parts or subassemblies required for making the product. Production data is concerned with how a product is produced i.e., it specifies the operation sequence and the machines required for each operation. Similar to describing a product structure using BOM, a bill-of-operations (BOO) can be constructed to represent the production structure of a given product.

Traditionally BOMs and BOOs are treated as separate data files by most computer based production systems. The BOM being primarily responsible for MRP and inventory management and the BOO being responsible for capacity requirements planning (CRP) and production Control. But a job is a statement of product, which require both BOM and BOO data. An effective control of a production job cannot be fulfilled without the integration of planning and control functions (Hong, 2006). A number of authors have demonstrated the merits of integrating the BOM and the BOO in production planning and control (Chang, 1997, Hastings et al., 1982 and Yeh, 1997).

To integrate the product structure data and operations information, a data model known as bill of manufacture (BOMfr) can be developed by combining the BOM structure and BOO structure. The BOMfr specifies the sequence of production operations required for making a product as well as the materials and resources required at each operation. In this way the unification of BOM and BOO can be achieved in a BOMfr structure.

The firm produces various types of turbines; the processing sequences of major parts of these turbines being mostly same. The user firm maintains the history of all the work orders that were processed on the shop floor in the form of BOMfr. Hence, whenever a new work order enters into the system, the manufacturing requirements (operation routing, material requirements, etc.,) of it are copied from the BOMfr of an equivalent work order available in the database. If the new work order has a different requirement then it takes non-trivial engineering effort and hence increased time in process planning. Additional job attributes such as number of pieces, due date and job precedence constraints are also created during the copying process. This production job data forms a basis for detailed operations scheduling and shop floor control. This provides a planning standard for making standard or recurring products.

There is a wide scope and variety of products that are being manufactured in the job shop. The manufacturer of job-shop under consideration uses a priority mechanism to resolve the resource contentions that arise on special purpose machines. The key objective of the manufacturer is to improve the resource utilization. This will correspond to minimizing the make-span and reducing the idle time of machines/resources. 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 firm 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.

4. Formulation of the Problem

The job-shop with capacity constraints may be formulated as follows: there are O number of jobs $O=\{o_0, o_1, o_2, ...o_N, o_{N+1}\}$ to be processed on a set of m machines $M=\{m_1, m_2, ...m_p\}$. Each machine m can process at most one job at a time. Each job O_n consists of a sequence of n_i operations that must be accomplished according to its manufacturing process. Each operation is assumed as non-preemptive.

Let o_0 and o_{N+1} represent fictious *start* and *end* jobs. Each job $o_N \in O$ needs to satisfy following properties:

1. A machine $m_p \in M$ processes job o_n and the processing time (*pt*) associated with the job o_n on machine m_p is given by equation (1).

$$pt(o_n); \{pt(o_0) = pt(o_{N+1}) = 0\} \tag{1}$$

2. Let PREC denote the set with precedence constraints for all jobs. For the scheduling problem that is under investigation, there is a *precedence set* associated with each job. That is, job o_n has a precedence set $PREC_n$. A routine is developed in *Visual Basic* for obtaining precedence sets associated with each job. Once the routine is run, the precedence's are populated into a *static master database* and these values remain unaltered unless there is an external change in the precedence.
3. Let PMC_k denote the set of all jobs that require machine m_k for processing. This is usually a static entry in the "master database".

Let *start*(o_0) denote the starting time of operation on job o_0 (=0). The indices *j and j' are used* to represent job. The objective to find an *optimal schedule for job-shop* that minimizes the makespan is represented in equation (2).

$$\min\left[\max_{\{o_j : j=0....N+1\}\in O}\left\{start(o_0) + pt(o_j)\right\}\right] \tag{2}$$

subjected to the constraints, equations $(3)-(10)$

$$start(o_j) \geq 0 \quad \forall j \in [0, N+1], \quad o_j \in O \tag{3}$$

$$start(o_j) - start(o_{j'}) \geq pt(j') \;\forall\; (j, j') \in PREC_j \quad o_j \in O \tag{4}$$

$$\begin{gathered} start(o_j) - start(o_{j'}) \geq pt(j') \\ \bigcup start(o_{j'}) - start(o_j) \geq pt(j) \\ \forall (j, j') \in PREC_j, \quad o_j \in O \end{gathered} \tag{5}$$

$$\begin{gathered} (j, j') \in PMC_m \\ \forall m \in M \end{gathered} \tag{6}$$

Capacity Constraints

Definitional constraint for finite machine capacity - availability

$$AV\_CAP_m = T * \eta_m \;\; \forall m \in M \tag{7}$$

Finite capacity constraint

$$\sum_{o\in O}\sum_{t\in[0,T]} x_{om}(t) * pt_{om}(t) \leq AV\_CAP_m \; \forall m \in M \tag{8}$$

Static capacity check

$$\sum_{o \in O} \sum_{m \in M} \sum_{t=0}^{T} \left[pt_{om}(t) * x_{om}(t) \right] \le T * |M| \qquad (9)$$

Binary Constraint

$$x_{om}(t) \in [0,1] \ \ \forall\, o \in O, \forall\, m \in M, \forall\, t \in [0,T] \qquad (10)$$

The formulation above is a representation of standard job-shop scheduling problem with an objective of minimizing the completion time with priorities assigned across various jobs. The Objective of the formulation shown in equation 2 indicates the sum of start time and processing time indexed with the operations and jobs.

Equation 3 indicates that, Start of an operation cannot occur before the planning horizon. In otherwords it should be greater than or equal to zero. Equation 4 indicates that the job (j+1) (i.e. successor job) cannot be taken for processing unless the predecessor job (j) is processed. The difference in start times of the successor and predecessor jobs should be atleast the processing time of the predecessor job. Equation 5 is a generalization indicating that all predecessor jobs in the predecessor UNION set should be finished before taking up a successor job. Equation 6 denotes the set (matrix) of successor and predecessor jobs which would require same machine for processing. To make sure that a machine combination is assigned to the predecessor and successor jobs.

We take into consideration of the machine efficiency while computing the actual available capacity for processing as shown in equation 7.

The finite capacity constraint shown in equation 8 indicates that the jobs indexed on to machine should not consume more than the available capacity (available capacity is computed taking into consideration of efficiency – as illustrated in equation 7)

Equation 9 is a generic check for the algorithm, that the total processing time booked across all jobs should fall with in the planning horizon. The cardinality of M indicates on an average number of parallel machines of identical capacity available for processing.

Finally the decision variable of our scheduling problem shown in equation 10 indicates which job to load on which machine on which time slot.

5. Priority Based Heuristic (PBH)

The model in this paper uses the forward check algorithm (FCA) in conjunction with the dynamic priorities of the customers to generate a realistic working schedule. The results obtained by the proposed model are compared with FCA and its variants namely, backward checking algorithm (BCA) and random checking algorithm (RCA).

Job shop scheduling problems are one of the most complex problems mathematically as well as practically. It is in this regard, researchers often try to explore the underlying problem and architect a solution procedure to solve the problem on-hand. The packaged heuristics like genetic algorithms, simulated annealing etc., helps to attack problems with a well defined framework. However, they fail to capture real world requirements and end up in an optimal but practically not feasible solution.

The heuristic proposed in this paper, falls into architecting a solution procedure right from scratch based on the intuition derived from our experience on shop-floor and our numerous interactions with the experts working on the floor in decision making. The steps detail a typical problem solving approach by a decision maker on shop-floor blending with some intelligence due to our heuristic and making it work with the best computing technologies.

The FCA is a general sorting and sequencing algorithm. It starts with no jobs and then fits the jobs honoring the precedence constraints and capacity constraints to get an optimal schedule whereas in case of BCA, we start with the end of planning horizon and drive backwards to get optimal schedule. RCA is used as a random check of working of algorithm. Here we start with any random choice of job and see the precedence and successor jobs and constraints attached to that, there by establishing an optimal solution.

The current focus of this paper on how best to integrate this heuristic with IT infrastructure over web to aid in realistic planning. To get a detailed overview of priority based scheduling heuristic and the establishment of bounds for the makespan; interested readers are referred to our earlier paper (Sandeep et al., 2008). The flow of the heuristic is discussed below:

5.1 Steps in the Scheduling Heuristic

Step 1: The details of new work order, its priority, start date, due date and equivalent work order are given as input.

Step 2: Process planning module retrieves the process plan of the equivalent work order from the Bill-of-manufacture (BOMfr) and updates this data to the new work order in the current database.

Step 3: Following the *apriori* sequence, the jobs and their operations to be scheduled are selected. While scheduling, the availability of required machines and the present load on those machines is considered.

Step 4: *Internal Clash Detection:* Check for the contentions of the operations in the same work order, which need to be processed on the same facility at the same instance of time. Resolve the conflict for the facility by considering the objective to find optimal make span with minimal inventory cost.

Step 5: External Clash Detection: Check for the clashes external to the work order, i.e., check for the possible cases of operations of different work orders conflicting for the same machine (waiting to be processed on the same facility). In this process the decision-making is done giving the preference to the highest priority customer as on that date.
Step 6: New Work Order addition: Whenever a new work order is added go to step (2) and repeat the process.

The results of the above scheduling procedure are the feasible start and finish times of each operation of the parts scheduled at the corresponding work place, calculated to the nearest minute. This constitutes a feasible, detailed production schedule for shop floor operations and control.

This work uses the real time data provided by a user firm that is a leader in turbine manufacturing in India. The data pertaining to steam and gas turbine job-shops is subjected to some cleansing before usage. The data collection and cleansing effort was non-trivial and was the base step to apply the proposed heuristic on the data. In particular job-shop scheduling with 10 different work orders with different priorities, release dates, processing requirements - in terms of time units is considered.

The results obtained through the proposed heuristic are presented in contrast with the results of FCA, BCA and RCA in Table 1.

Table 1. Comparison of makespan obtained using the proposed heuristic against FCA, BCA and RCA

S.No	Work order No	Initial Priority	Release Date (in days)	Promised Date (in days)	Our heuristic makespan (in days)	FCA Makespan (in days)	BCA makespan (in days)	RCA makespan (in days)
1	WONO1	1	0	390	213	180	180	180
2	WONO2	3	25	457	349	372	212	372
3	WONO3	5	98	530	415	490	319	490
4	WONO4	4	123	570	467	543	387	543
5	WONO5	9	76	520	430	497	408	497
6	WONO6	10	44	500	423	531	471	531
7	WONO7	6	95	479	302	518	586	518
8	WONO8	2	0	400	271	250	661	250
9	WONO9	7	34	608	398	597	668	597
10	WONO10	8	85	662	445	711	703	711

The following interesting insights are obtained from the rigorous experimentation.

1. The proposed heuristic performs better than FCA, BCA and RCA in overall terms. Figure 1 shows the graphical comparison of the makespan results using the proposed heuristic Vs other algorithms namely, FCA, BCA and RCA.

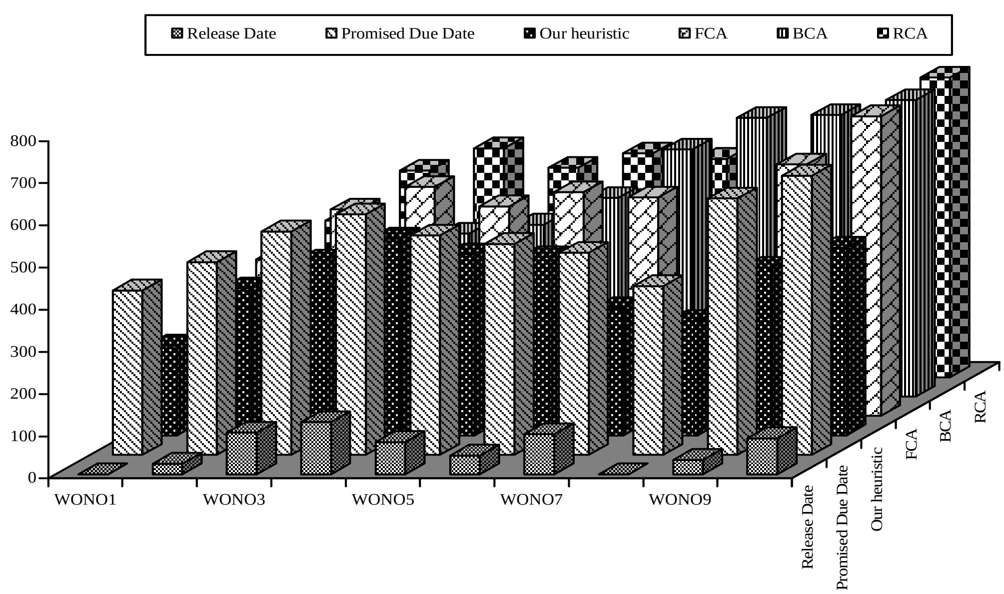


Figure 1. A graphical comparison of makespan with the proposed heuristic Vs *FCA, BCA and RCA*.

2. FCA outperformed BCA in the later half of planning horizon - while in the former half BCA performed better.

3. The results of FCA and RCA are coinciding- due to the fact that in the current testing setup the precedence constraints are *hard coded*. RCA would start with any random point in the entire operation sequence, however should end up with the start point of FCA for resolving contention.

5.3 Integration of CRP and Scheduling

Scheduling is responsible for making detailed, executable schedules and it has to assign finite capacity resources to production operations as well as determine their order of execution. The main objective of integrating scheduling and CRP is to ensure the effective utilization of capacities and to keep bottlenecks at bay. The purpose of CRP is to find the underloads and overloads on various machines and to see that these loads must be normalized either by pulling the work ahead or pushing the work back to later time periods. This paper proposes the implementation of CRP integrated with the scheduling. The heuristic presented in this section develops a feasible schedule. Based on the availability of the work place/work center, the start date of each operation is calculated.

If a part is required to be processed on a particular combination of work center/ work place, then calculate the idle time available between two consecutive operations performed on all such machines. Find the machines for which idle time is more than the operation time of the part. Find the first available machine, and if there is more than one such machine available on the same day, then assign the part to the least loaded machine in that month.

In the traditional approach, CRP determines the load profiles by assigning the jobs to the preferred machine first, but when capacity problems occur, jobs can certainly be reassigned to alternate machines. Where as in the proposed work, before the machines are loaded, there previous load is calculated and if the machine utilization is below the assigned limit, then the job is assigned to it, otherwise, it is assigned to the other least loaded alternate machine based on the availability. If there is no alternate machine available, then job is postponed till the required machine gets freed. In this way all the overloads and under loads that follow, are eliminated before they occur and also the load is normally distributed to all the similar machines in a given work center/ work place combination.

Table 2 presents the result of integration of scheduling with CRP for the problem consisting of 10 Work orders with 146 jobs and 4167 operations to be processed on 82 machines. The measure of workload smoothness can be evaluated from the load profile of each work place. Fig. 2 shows such a profile over the scheduling horizon. The monthly load requirement is plotted against the number of months in the scheduling horizon and the average workload requirement is also indicated.

Table 2. Estimated workloads on a work place with and without integration of scheduling and CRP over a given time horizon

Month	Workload (hrs)	
	With CRP	Without CRP
1	308.3	461.7
2	275.0	400.0
3	325.0	295.0
4	167.0	361.7
5	246.6	466.7
6	316.7	417.5
7	350.0	383.3
8	333.3	425.0
9	283.3	70.0
10	333.3	31.6

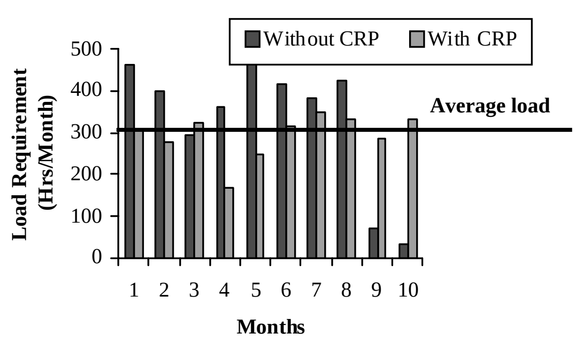


Figure 2. Work place load profile with and without implementing CRP

From this profile, the workload smoothness (WLS) is calculated using equation (11)

$$WLS = 1 - \frac{Area\ above\ average\ workload}{((Average\ workload) * (Length\ of\ scheduling\ horizon))} \qquad (11)$$

The closer this value is to 1, the smoother the work place loading. A threshold of 300 hours is fixed as the average workload acceptable for a machine per month (assuming unforeseen factors other than the machine breakdown, preventive maintenance etc, which may influence the working hours).

The workload smoothness calculated from the above profile without implementation of CRP is 0.72 whereas with the integration of CRP it is found to be 0.953. This shows that there is a significant improvement in the workload smoothness thru integration of CRP with scheduling.

6. Development of online Scheduling Support System

In the present research work the online scheduling system is developed by integrating with the World Wide Web for improving its accessibility by users of the different plants of the firm located at geographically dispersed places. The system is developed in two phases.

6.1 Phase-I: Stand Alone Scheduling System

In the first phase a standalone scheduling system was developed integrating scheduling with CRP. The system is developed using Visual Basic for executing the application program and Oracle as database management system. The application program consists of priority based scheduling heuristic, whereas, the oracle database consists of process plan, customer database and machine database.

A typical graphic user interface screen (scheduling input screen) of the standalone Decision Support System (DSS) for generating the schedule of a new work order is shown in Figure 3.

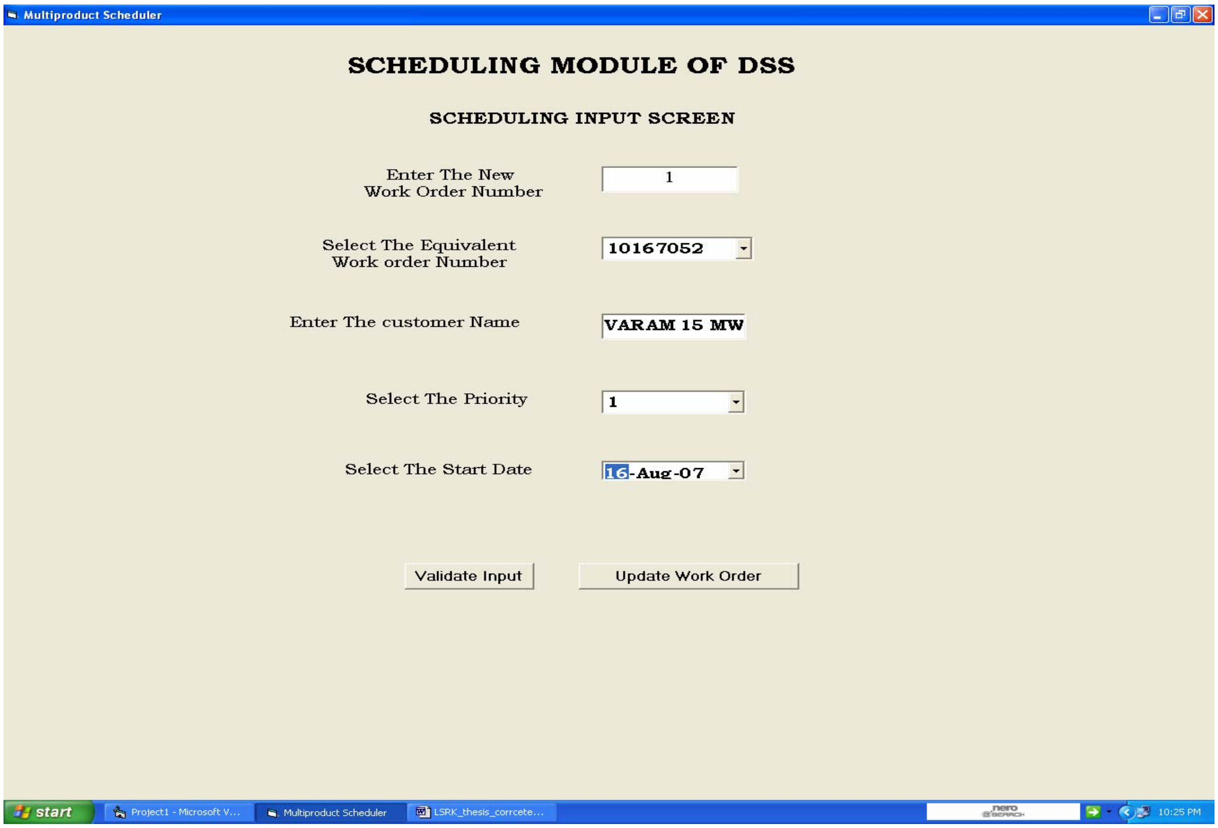


Figure 3. Scheduling input screen

6.2 Phase – II: Web Enabling of DSS

In the second phase as per the requirements of the user industry, the developed standalone DSS is web enabled. This work is based on the client /server approach with the three layer architecture. The three layers are *presentation layer*, *operational layer* and *database layer*. Figure 4 shows the structure of the method, which would enable the user to run the DSS and obtain the results from a remote location.

Presentation layer: The first layer is the presentation layer which consists of web browsers. The first layer allows the authorized users to interact with the Decision support system located at a remote place. It is developed using Java Server Pages (JSP). The JSP pages contain all the necessary graphical user interfaces (GUI's) between the client and the server. It allows authorized users to select the desired parameters for the scheduling and customers for placing orders and knowing the status of the order

Operational layer: The middle layer is the operational layer which consists of two logical layers, one is the web application program and the other is the standalone application program. The web application program consists of web service clients and struts frame work. Struts framework is a standard for developing well-architected web applications. It will process request from the client and interacts with the web service client. The web service client communicates with the web services present in the standalone application program. The standalone application program consists of the web service and the Visual Basic (VB) program. The web services executes the VB program and sends the response to the web service client. The VB program consists of code for executing the scheduling heuristic.

Database Layer: The third layer is the database layer. The database layer manages the relevant data pertaining to the process plan of work orders i.e manufacturing database, customer database and machine database. In this package, the entire database is remotely deployed on a computer that is physically different and separate from the web server and application server.

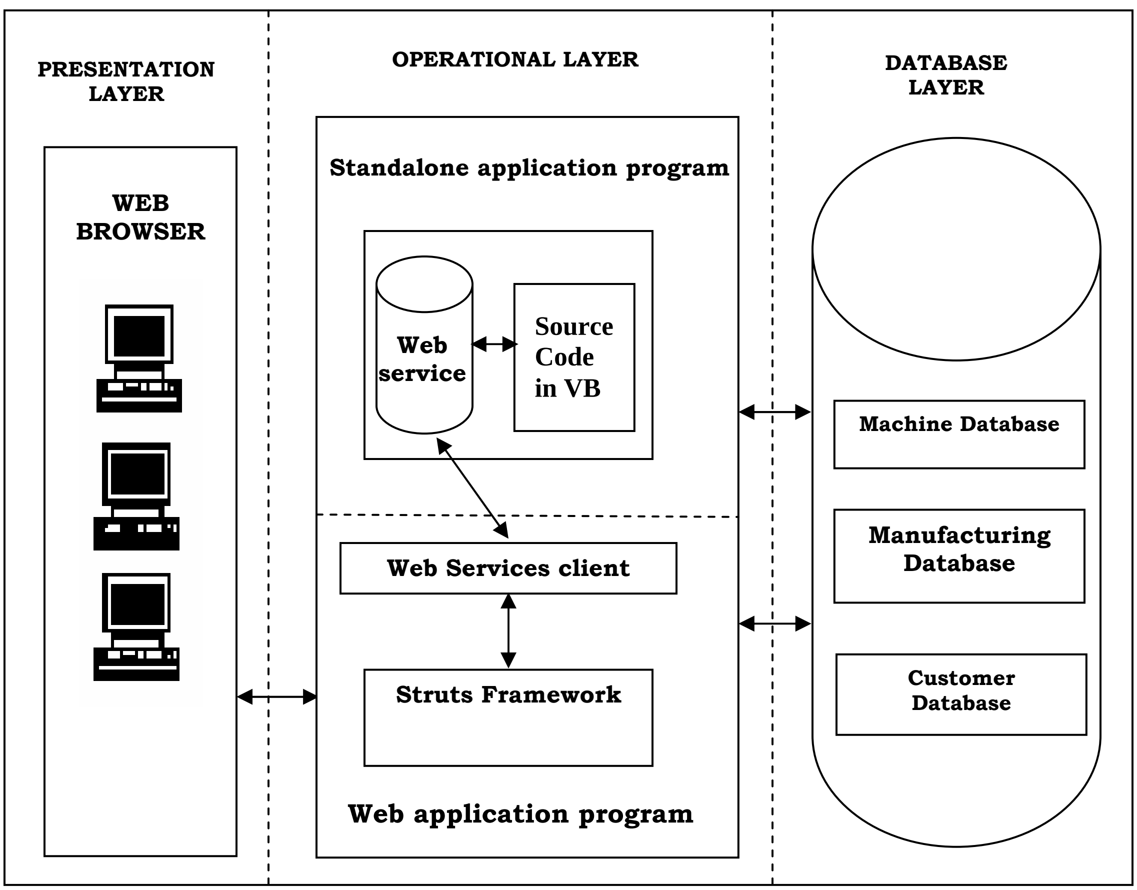


Figure 4: Three-Tier Architecture of the online scheduling support system

6.3 Graphical User Interfaces of Online Scheduling Support Systems

The online scheduling support system has user friendly graphic interfaces which help the user in decision making. Some of them are discussed below:

New Workorder Details: This GUI allows the user to add any new customer order by giving the priority and start date for any customer order. The software runs the schedule program and predicts the expected delivery date of the workorder. Figure 5 illustrates the new workorder details web page.

Component Schedule: This web page allows the user to see the schedule of a given part belonging to a PGMA and WONO. The accessibility of this GUI is given to production manager and top management. The component schedule web page is shown in Figure 6.

Workplace loading: This GUI allows the user to know the loading of a particular machine on the shop floor for a given time horizon. The accessibility of this screen is given to only middle and top level management. Figure 7 illustrates workplace loading chart.

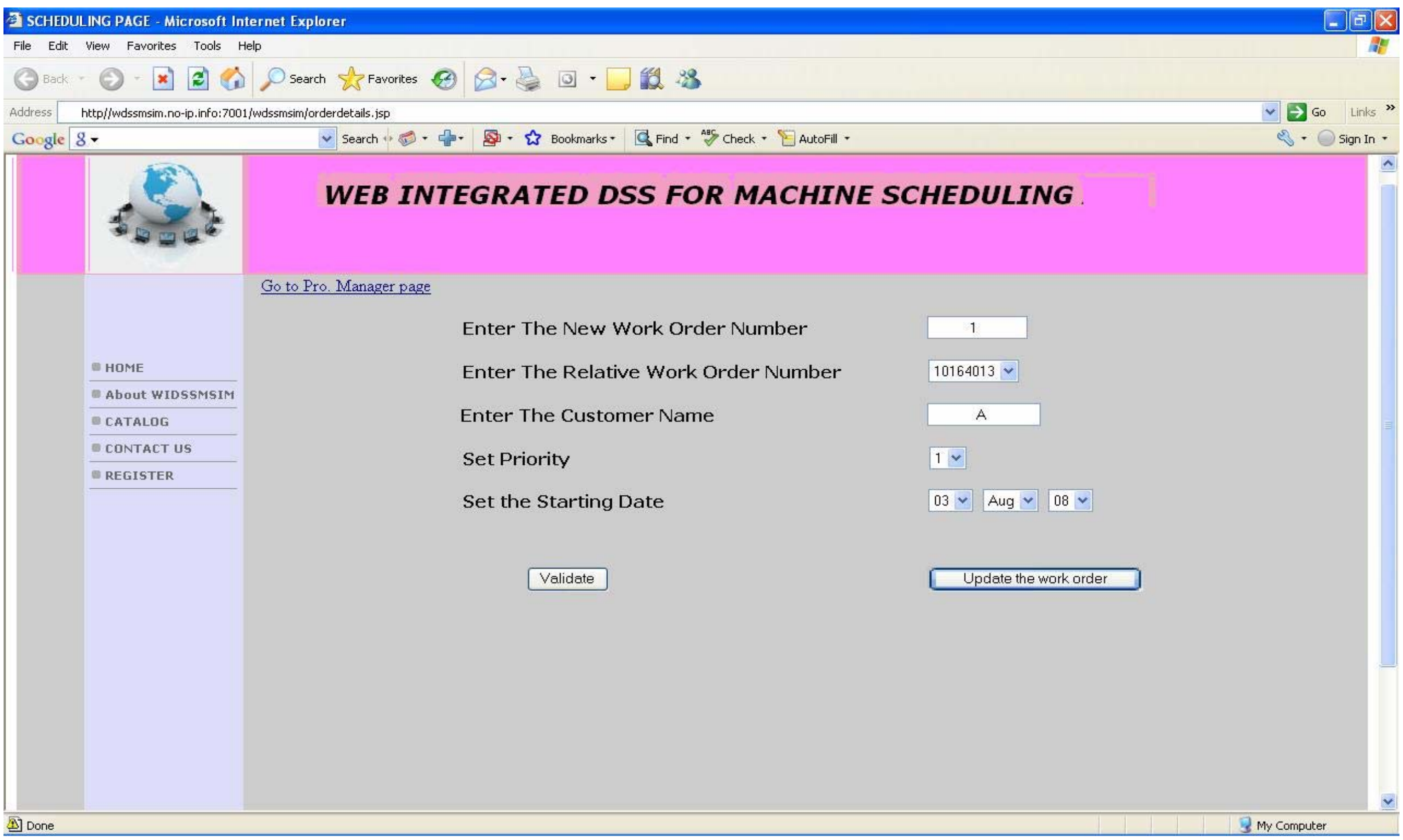
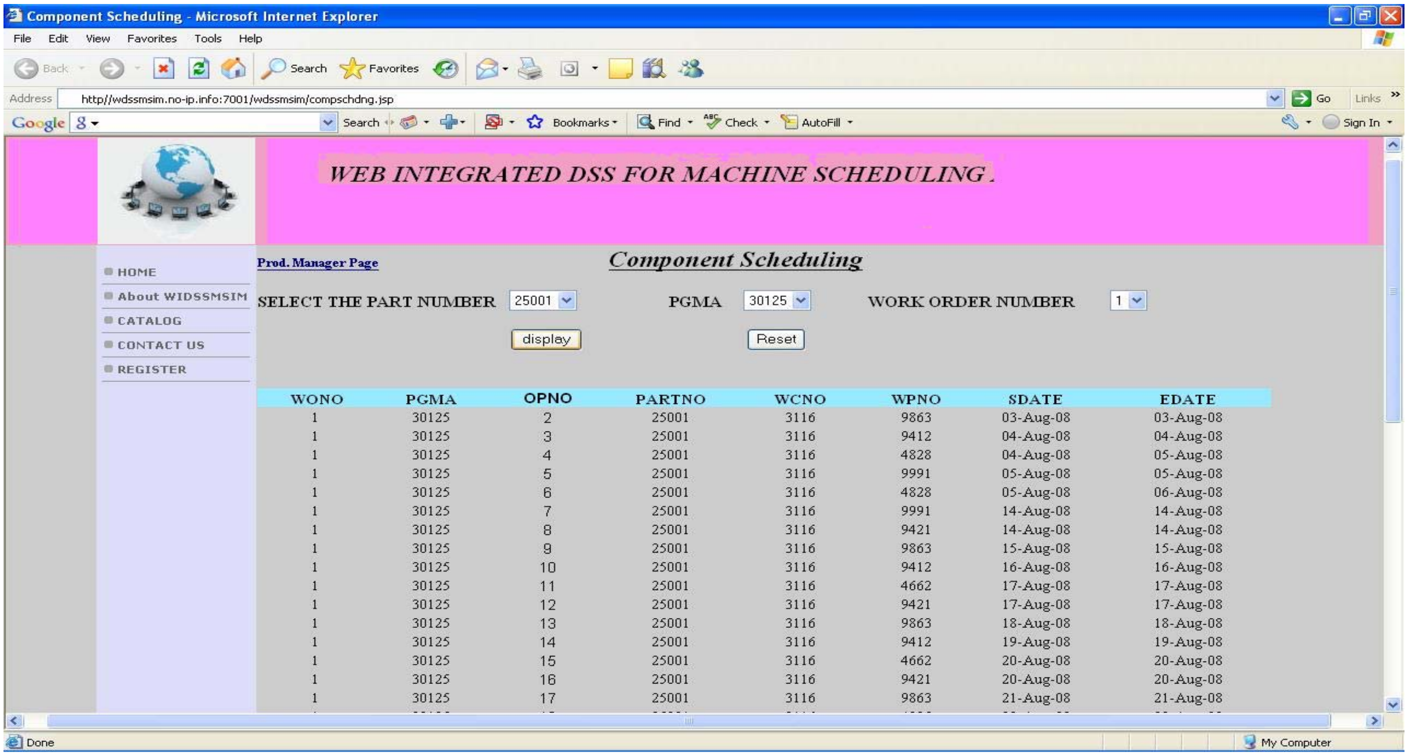
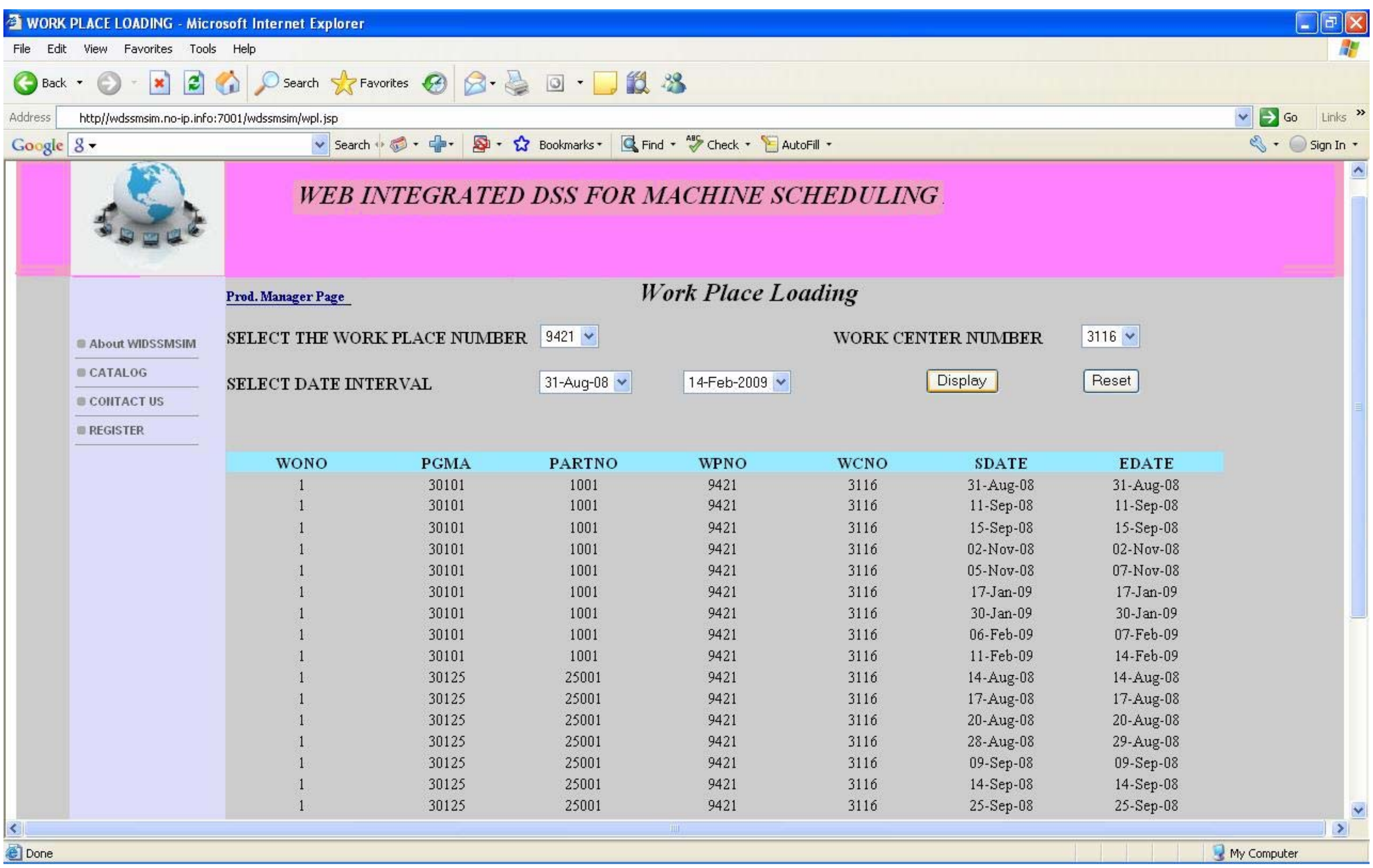


Figure 5: New workorder details web page



WONO	PGMA	OPNO	PARTNO	WCNO	WPNO	SDATE	EDATE
1	30125	2	25001	3116	9863	03-Aug-08	03-Aug-08
1	30125	3	25001	3116	9412	04-Aug-08	04-Aug-08
1	30125	4	25001	3116	4828	04-Aug-08	05-Aug-08
1	30125	5	25001	3116	9991	05-Aug-08	05-Aug-08
1	30125	6	25001	3116	4828	05-Aug-08	06-Aug-08
1	30125	7	25001	3116	9991	14-Aug-08	14-Aug-08
1	30125	8	25001	3116	9421	14-Aug-08	14-Aug-08
1	30125	9	25001	3116	9863	15-Aug-08	15-Aug-08
1	30125	10	25001	3116	9412	16-Aug-08	16-Aug-08
1	30125	11	25001	3116	4662	17-Aug-08	17-Aug-08
1	30125	12	25001	3116	9421	17-Aug-08	17-Aug-08
1	30125	13	25001	3116	9863	18-Aug-08	18-Aug-08
1	30125	14	25001	3116	9412	19-Aug-08	19-Aug-08
1	30125	15	25001	3116	4662	20-Aug-08	20-Aug-08
1	30125	16	25001	3116	9421	20-Aug-08	20-Aug-08
1	30125	17	25001	3116	9863	21-Aug-08	21-Aug-08

Figure 6: Component schedule web page



WONO	PGMA	PARTNO	WPNO	WCNO	SDATE	EDATE
1	30101	1001	9421	3116	31-Aug-08	31-Aug-08
1	30101	1001	9421	3116	11-Sep-08	11-Sep-08
1	30101	1001	9421	3116	15-Sep-08	15-Sep-08
1	30101	1001	9421	3116	02-Nov-08	02-Nov-08
1	30101	1001	9421	3116	05-Nov-08	07-Nov-08
1	30101	1001	9421	3116	17-Jan-09	17-Jan-09
1	30101	1001	9421	3116	30-Jan-09	30-Jan-09
1	30101	1001	9421	3116	06-Feb-09	07-Feb-09
1	30101	1001	9421	3116	11-Feb-09	14-Feb-09
1	30125	25001	9421	3116	14-Aug-08	14-Aug-08
1	30125	25001	9421	3116	17-Aug-08	17-Aug-08
1	30125	25001	9421	3116	20-Aug-08	20-Aug-08
1	30125	25001	9421	3116	28-Aug-08	29-Aug-08
1	30125	25001	9421	3116	09-Sep-08	09-Sep-08
1	30125	25001	9421	3116	14-Sep-08	14-Sep-08
1	30125	25001	9421	3116	25-Sep-08	25-Sep-08

Figure 7: Workplace loading chart

7. Conclusions

We propose a concept of workload smoothening in high mix job shop. Our approach has generated the workload which is smooth and predictable. The power of predictability via smoothening helps in a better real time decision making. This approach is tested as pilot implementation in a turbine manufacturing firm yielding satisfactory results in a reasonable time (less than 15 minutes for 10 work orders). Another significant contribution of our research work is web enabling the scheduling support system. This helps users of the different plants of the firm located at geographically dispersed places to operate the scheduling system using the features of World Wide Web (WWW). The current research work can be extended by integrating the process plan changes into the work-load smoothening. Extending the scheduling problem and underlying decision framework to a stochastic setting with a mix of job-shop and batch-shop can also be considered as direction for future work.

Nomenclature

Sets
I: Part/Job
J: Machine
T: Week

Indices
o: Index for job
m: Index for machine
t : Index for week

Parameters
pt_{om}: Processing time of o^{th} job on m^{th} machine.
T : Length of planning horizon in weeks
$\eta_m (t)$: Availability of machine m in week t

Decision Variables
$x_{om}(t)$: Binary Variable = 1 if o^{th} part is processed on m^{th} machine in week t, = 0 otherwise

Terms
AV_CAP_m= Available Capacity of m^{th} machine during the planning horizon

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