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SHOP FLOOR SCHEDULING WITH SIMULATION BASED PROACTIVE DECISION SUPPORT

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ABSTRACT

This paper involves the study of a simulation based proactive decision support module for the shop-floor scheduling of the Plastic Processing Section (PPS) at Bharti Telecom Limited, Gurgaon, India. The flow of material and information in this shop is highly complex as it involves multiple product parts, sequence dependent setup, molding machine specifications, mould restrictions etc. with a variety of scheduling and operational choices. The shop floor planning and scheduling decisions are being exercised manually and there is enough scope of using this simulation based tool to improve the shop-performance. In this work, efforts have been made to simulate the scheduling environment of this section. The performance of the shop depends on various parameters such as initial conditions of the machines, the load on the system, sequencing rule etc. Also the user requirements are so varied and situation dependent that it requires the use of simulation techniques to get a better schedule. Further, there are some findings based on the simulation experiments, which are in the process of implementation in the shop.

1 INTRODUCTION

In recent years, there has been a tremendous upsurge of interest in manufacturing systems design and analysis. Large industrial companies have realized that their manufacturing facilities can be a source of tremendous opportunity if managed well or a huge corporate liability if managed poorly. The modern environment of discrete parts manufacturing is sophisticated and intensely competitive. It is characterized by short product life cycles, high product diversity, and customer's demand for both excellent quality and timely delivery. If the production operation is capable of responding to these challenges, manufacturing can be a source of real competitive advantage for the business. Otherwise, the manufacturing process could become an inflexible and expensive corporate liability, and business strategists might do well to consider external sourcing of company products.

In manufacturing, the challenges are to develop a finely tuned process, capable of meeting the cost, quality, variability and time pressures imposed by the marketplace. Our primary objectives in this work include the reduction of manufacturing lead-time to the minimum possible, and achievement of a high level of process control. The benefits accruing from such efforts should include greater flexibility and responsiveness, better use of manufacturing resources, reduced inventories levels, and faster turn around on customer orders.

Advanced Information Technology (IT) now brings the realization of such objectives within reach. It makes explicit and feasible, the desire to reduce manufacturing lead times to a level approaching the actual time spent in material conversion on the shop floor. However, the application of sophisticated technology alone is unlikely to yield a durable and efficient shop floor strategy. On the shop floor, there is a need to link and refocus all of the discrete stages, which make up the process, so that the total manufacturing operation can be optimized (Bauer et al. 1991). Hence the focus of this paper is on operational level production planning and scheduling; normally referred to as shop floor control.

2 THE PROBLEM

The purpose of this work is to present the use of a simulation based decision support tool in shop floor scheduling and control of the Plastic Processing Section at Bharti Telecom Limited, Gurgaon, India. The plant produces telephone terminals of the order of one million telephones per year with a variety of four models. There are a wide variety of operational, planning and control decisions required from the shop floor manager due to complex information and material flow in the shop. Currently, the scheduling decisions are taken manually using intuition. Thus, there is much scope for improvement by using simulation.

The problem is to assist in shop floor scheduling for the Plastic Processing Section with a simulation based decision support tool. It should help in taking planning and control decisions effectively and efficiently with the given current status of the shop floor, in tackling uncertainties of the shop in a better way, in providing a sufficiently comprehensive picture about the system at any point of time, in finding the tardy / late orders, and in achieving a better resource utilization.

Rogers and Flanagan (1991) give emphasis on the online simulation of manufacturing scheduling which can operate as a "what now" tool instead of a "what if" tool. Online simulation offers the sales and marketing functions the capability to reliably predict order completion times for customers and support to real time scheduling decisions. Goel (1994) developed a general-purpose simulation tool to enable the user to model flow lines, with provisions for modeling of flexibility. The aim was to support the end user in decision making in the fields of planning, scheduling and control of manufacturing systems.

The Plastic Processing Section (PPS) is the backbone of the industry, in which entire molding of the plastic parts of telephones is done through Injection Molding machines. The raw material consists of plastic granules like ABS (Acrylonitrile Butadiene Styrene), PMMA (Poly Methyl Methacrylate), PC (PolyCarbonate Resins) etc. Some secondary operations like Punching, Printing etc. are also done there. There are seven Injection Molding Machines in this section, which includes three SP180 machines, one SP80, one SP30, one LTM150, and one SPEEDY130. In addition, there are two ovens/preheaters, three presses, one granulator, and one buffing machine besides a no. of trolleys and jigs & fixtures for printing. There are four different models (Sapphire, Premier, Sleek, and Coral) of the phones to be produced. Sapphire has 8 different moulds to produce its various subparts; Premier has 14 different moulds; and Sleek and Coral have 9 different moulds for each. Each mould has its own specification in terms of ability to be loaded on a particular injection molding machine. Each model has to be produced in around six different colors. In summary, forty different parts are molded in this section, with one mould for each part, having constraints on machine and raw material to be used.

3 SHOP FLOOR SCHEDULING

The scheduling of PPS can be considered as job shop scheduling, known more commonly in practice as shop floor control, which is the set of activities in the shop that transforms inputs (a set of requirements) to outputs (products to meet those requirements). Much of this is concerned with the sequencing issue on the shop floor with some objectives (Baker 1974).

One of the difficulties of scheduling is that many, often conflicting, objectives are present. Ideally, the objective function should consist of all costs in the system that depends on scheduling decisions. In practice, however, such costs are often difficult to measure, or even to identify completely. Nevertheless, three types of decision-making goals seem to be prevalent in scheduling: efficient utilization of resources, rapid response to demands, and close conformance to prescribed deadlines. Frequently, an important cost-related measure of system performance (such as machine idle time, job waiting time or job lateness) can be used as a substitute for total system cost. Some of the most common objectives of scheduling are (Baker 1974):

1. Meet due dates,
2. Minimize average flow time through the system,
3. Minimize the total number of tardy jobs,
4. Minimize the average tardiness of the jobs,
5. Minimize the maximum tardiness of the jobs,
6. Minimize work-in-process (WIP) inventory,
7. Provide for high machine/worker time utilization (Min. machine/worker idle time), and
8. Minimize production costs.

In these objectives, (1)-(5) are aimed primarily at providing a high level of customer service, and (6)-(8) are aimed mainly at providing a high level of plant efficiency.

In a single machine scheduling problem, there is a collection of jobs that must be processed on the machine and each job has associated with it a processing time and a due date. Some common sequencing rules for such a situation are: FCFS (First-Come, First-Served), SPT (Shortest Processing Time), LPT (Longest Processing Time), EDD (Earliest Due Date), and CR (Critical Ratio) (Nahmias 1989).

In FCFS, the sequencing of jobs is done according to the arrival order of the jobs at the work station. In SPT, the jobs are sequenced in a order of increasing processing time of jobs. In contrast, LPT gives the job sequence according to the decreasing order of the processing times. EDD sequences the jobs in an increasing order of their due dates.

Critical ratio scheduling requires forming the ratio of the processing time of a job divided by the remaining time until the due date, and scheduling the job with the largest ratio next. The idea behind CR scheduling is to provide a balance between SPT, which only considers processing time, and EDD, which only considers due dates. The ratio will grow smaller as the current time approaches the due date, and more priority will be given to those jobs with longer processing times. One major disadvantage of the method is that the critical ratios need to be recalculated at each time a job is scheduled.

The SPT rule minimizes the mean flow time, mean waiting time, and mean lateness (all of these measures are equivalent) for a single machine sequencing and also minimizes the work-in-progress (WIP) (Pinedo 1995). LPT may also prove to be a good alternative for maximizing machine utilization. The EDD rule gives an optimal schedule according to minimizing the maximum tardiness of the jobs in a single machine sequencing scenario. But, in case of a job shop, hardly any single rule will come out as the best in every situation.

4 DEVELOPING A DECISION SUPPORT TOOL

The basic user requirement is that the module should be able to generate a feasible schedule i.e., allocate jobs to machines and spell out the resources (time, material, etc.) for this schedule, using discrete event simulation (Law and Kelton 1991). Some of the other requirements are as raw material constraints, preventive maintenance scheduling, focus on the color change order (i.e., from light color to dark color) to minimize the color change time, while scheduling. The module has the ability to re-schedule the system in sudden changes of the conditions such as raw material shortage, sudden breakdown etc. Further, as time progresses, there is always a difference between the actual status on the shop floor and the schedule, which increases with time. The schedule is enabled to re-schedule based on the current status of the shop floor so that both, schedule and current status matches with each other.

The shop floor control module is a scheduling support tool i.e., it provides a support to the user so that the decision is taken after comparing the different available options of scheduling which are better in respect to the different aspects such as due dates, overhead costs, minimum flow time, raw material requirements etc. In development of this simulation based decision support tool, the key points related to the shop are as:

- All the moulds cannot be loaded on all the machines. Each mould has a certain set of machines on which it can be loaded. To include this, a specific coding of the moulds is done. The three most vital elements of the model developed for the PPS are the machines, the jobs and the moulds, representing the resources, tasks and the inter link within them. The object dependency diagram of these fundamental features of the model is given in Figure 1.
- CNC Machines are given the top most priority while scheduling. The aim is to keep them busy for maximum time. There are two CNC machines in the shop, namely Speedy130 and LTM 150. They are given the first priority whenever the scheduling is done.
- All setup times are constant and independent of the machine & mould. The set-up times depend on whether there is a mould change or a color change. There are different color change times associated with a color change from light to dark or a color change from dark to light. Table 1 summarizes the set-up times collected from the shop floor.

The user input consists of the current status of the shop floor as well as the jobs to be produced. The user has also to specify the particular sequencing rule.

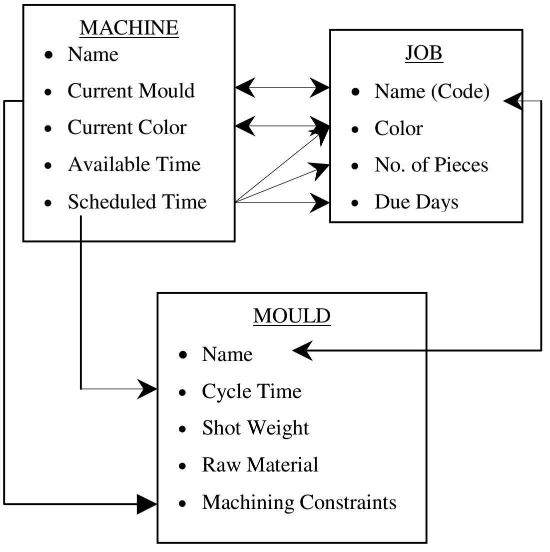

Figure 1: Object Dependency in the Model

Table 1: Setup Times in Color Change

Color Change (L-D)	Color Change (D-L)	Mould Change	Time (min)
Yes	No	No	30
No	Yes	No	120
No	No	Yes	90
Yes	No	Yes	90
No	Yes	Yes	120

5 RESCHEDULING

The utility of any shop floor control module cannot be complete without the flexibility of rescheduling or control decisions, which involves taking stock of the situation at any time during the course of simulation and to be able to reschedule given an unexpected situation. Some of the conditions that may require rescheduling are:

- Breakdown / Unavailability of specific machines.
- Expedite some other important order.
- Change of preference (i.e., change of objectives of the user).
- Some moulds are not available for the entire / partial period.
- Raw material availability.
- Labor availability.

This feature of rescheduling helps the user to correct the discrepancy between the simulated schedule and the actual shop floor status at regular intervals of time. For rescheduling the shop, an actual snap-shot of the factory status is fed as the initial setups and production quantity remained is adjusted accordingly. Then, using simulation model for the new shop floor status, an appropriate schedule is selected.

6 PERFORMANCE PARAMETERS

For evaluating the performance of different generated schedules for the shop floor at PPS, the following performance parameters are taken in to consideration: average flow time, make span time, average capacity utilization, number of tardy jobs, maximum tardiness, and average tardiness of each part.

- Average flow time of each part is calculated as the sum of flow times of all parts divided by the total number of parts. The flow time of the part i is the time elapsed from the initiation of the first job on the first machine to the completion time of job i. Equivalently, it is the amount of time that job i spends in the system. Let c be the end of set-up for a job on a machine, then, Flow time of i^{th} job = c + i*(processing time of each part), Total flow time for n parts = $\sum_{i=1}^{n}$ (flow time for i^{th} part).
- Make-span time for the schedule is the flow time of the job which is completed last i.e., the completion time of the last job.
- The average capacity utilization is computed simply based on the machine idle time, which included set ups.

  Average capacity utilization

$$= \frac{\text{total run time - sum of (idle time + setups)}}{\text{total run time}}.$$

- Tardiness is the positive difference between the completion time and the due date of a job. A tardy job is one that is completed after its due date. The number of tardy jobs and the maximum tardiness are calculated from the simulation results of the generated schedule.
- The average tardiness is computed as the total tardiness divided by the total number of jobs. Let t be the due time of the job in consideration. Then if t occurs before c, all the jobs are tardy. If t occurs after c and (t - c) / (processing time of each part) is more than n (the number of parts in that job), then no job is tardy. In all other cases, some parts of the job would be tardy and can be found by $n-(t-c)/$ (processing time of each part).

  Tardiness of i^{th} job (if it is tardy)

  = c+ i * (processing time of each part) -t.

  Total Tardiness for a job of n parts

$$= \sum_{\text{all tardy jobs}} \text{Tardiness of } i^{th} \text{ part.}$$

7 VARIFICATION, VALIDATION, AND EXPERIMENTATION

The developed module is verified by comparing the simulated schedule for various simple case with the manually generated schedules. Validation of the model is done with different inputs from various factory personnel of plastic processing section and planning and control section. Further, a large variety of experiments were conducted on the developed shop floor scheduling model and some interesting results are presented here in the following sections, which are of great improvement scope for the factory and are under consideration of implementation.

7.1 Various Scheduling Modes

The experiments are conducted with four different scheduling modes, with proportional quantity to be produced as shown in Table 2. From the point of view of easiness in implementing at factory, the minimum scheduling mode is taken as of one day and maximum as of 30 days. The results of the experiment are shown in the Figure 2 in form of the bar charts with varying sequencing rules.

Figure 2 clearly shows that the make-span time does not follow the same proportion as of the quantities to be produced, but it becomes better as the quantity increases e.g., the make-span of 30 days schedule is much less than thirty times of the make-span of one day schedule. Similarly, the maximum machine utilization (87.45 %) is achieved with the 30 days schedule by LPT sequencing rule. For this schedule, LPT also gives minimum make-span time and minimum production cost. Therefore, the large scheduling mode with LPT is in consideration of application in the shop for better utilization in over all terms of cost, make-span time and m/c utilization. However, in running the large scheduling mode, there will be more chances of deviation in the generated schedule and actual shop floor status, therefore the rescheduling feature of the model has to be used from time-to-time, in order to keep the schedule and shop floor status updated.

7.2 Different Product Mix

This experiment is conducted to find out the best combination of different products such as Sapphire, Premier and Sleek, so that make-span time remains less than seven days for maximum capacity utilization of the shop. It is assumed that the total production should be at least 15000 phones per week and the minimum lot size is 500 phones. All these combinations have the same due days (7 days) and same color (black) for all the models as shown in Table 3. The make-span time and machine utilization are plotted in Figure 3 against various sequencing rules and product mixes.

The make-span is minimum for the combination ‘E’ with LPT rule and also it has very high machine utilization

Table 2: Different Scheduling Modes

S. No.	Schedul-ing Mode	Sapphire (Due-Days)	Premier (Due-Days)	Sleek (Due-Days)
1.	1 Day	500 (1)	500 (1)	500 (1)
2.	2 Days	1000 (1)	1000 (2)	1000 (2)
3.	7 Days	3500 (6)	3500 (7)	3500 (5)
4.	30 Days	15000 (20)	15000 (30)	15000 (25)

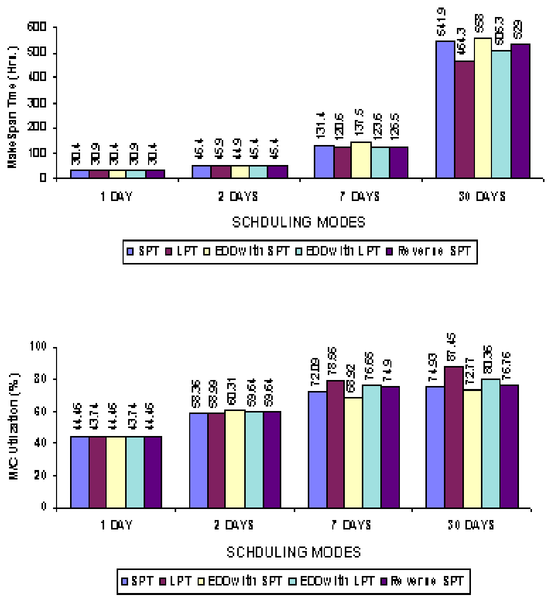

Figure 2: Performance Parameters for Various Sequencing Rules under Different Scheduling Modes

Table 3: Product Mix Data

	A	B	C	D	E	F	G
Sapphire	5000	4500	4500	5000	5500	5000	5500
Premier	5000	5500	5000	4500	4500	5500	5000
Sleek	5000	5000	5500	5500	5000	4500	4500

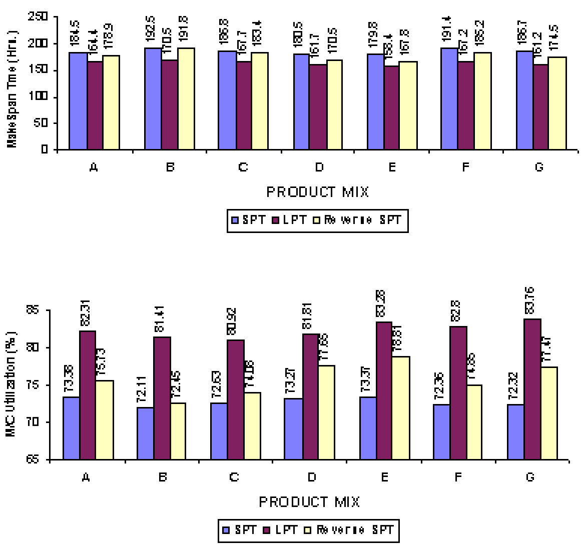

Figure 3: Performance Parameters for Various Sequencing Rules for Varying Quantity of Total Mix

(83.28%). For all the combinations LPT give the maximum average capacity utilization in general, with combination 'G' having highest value (83.76 %). Generally, LPT rule gives the minimum make-span time and maximum capacity utilization, opposite to the common expectation.

7.3 Partial Unavailability of Machines

In this experiment, initial mould condition was same and the effect of partial non-availability of the machines was studied. Each machine was delayed by four hours at a time. The load on the system was kept at 1000 Sapphire (grey-1 day) + 1000 Premier (brown-2 days) + 1000 Sleek (pink-2 days) for two days scheduling of the shop.

The bar charts are plotted in Figure 4 for Makespan time and m/c utilization against different machines. The delaying of SP-30 machine has the worst effect on the system because in the schedule this machine gets free at the last. Therefore, SP-30 machine is very critical for the shop. Also, EDD with SPT gives minimum Makespan time and maximum capacity utilization for all the machines except SP-30. So this machine should be utilized very efficiently and effectively, by giving the priority in the generated schedule.

8 CONCLUSIONS AND FUTURE WORK

This paper contains the study of development and application of shop floor decision support tool which would givethe shop floor manager of Plastic Processing Section of Bharti Telecom Limited, the flexibility and the support to take operational level planning and control decisions effectively. The flow of materials and information in this shop is complex with multiple parts, a choice of different objectives by the manager and the uncertainties associated

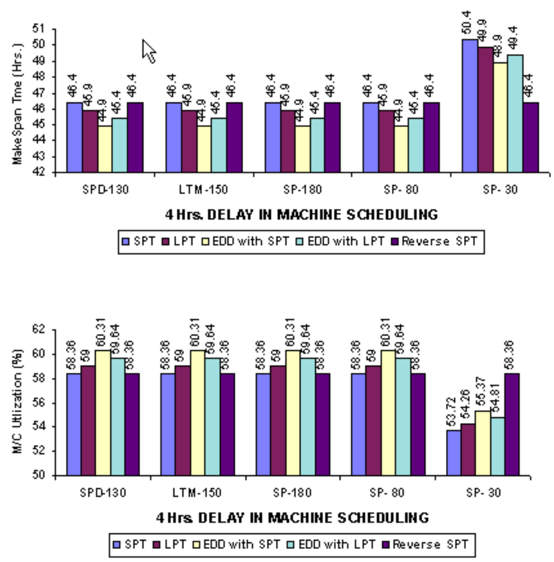

Figure 4: Performance Parameters for Various Sequencing Rules for 4 hrs. Delay in Scheduling of Different Machines

with them. Due to these complexities, there is a wide scope of using a simulation based decision support tool in assisting the users to improve the shop performance.

This simulation based shop floor scheduling module can act not only as a "what if' tool for the user, but also as a proactive decision support tool that can act as a "what now' tool. Further, a variety of simulation algorithms ensured that the user would have a schedule that would match desired preferences in terms of lead time, capacity utilization, flow time, average tardiness, maximum tardiness, etc., in real conditions. A variety of experiments are carried out on this shop floor scheduling module. These included experiments to verify the simulation model as well as to extract useful results. From the experimentation work done, it is clear that the results of any experiment are highly dependent on the initial conditions of the shop and the load on the system i.e., parts to be produced. Different sequencing rules give the better results for different conditions and different performance parameters. So for a user's point of view, for given conditions of the shop, simulations can be done and depending on his performance parameters, the better solution can be chosen.

The future work involves the all-important complete feedback from the user on the proposed implementation findings, the study of the impact of material availability and space availability i.e., inclusion of an inventory control system in the shop floor control module, identification of alternative optimization strategies and intelligent heuristics with their implementation, module extension for providing the flexibility to alter the number of machines, moulds, models etc. Further, the module can be integrated with other modules, like the assembly section module, the stores module to act as a complete control module on the lines of ERP (Enterprise Resource Planning).

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