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SCHEDULING IN PRESENCE OF UNCERTAINTY AND SUB GROUPING. A CASE STUDY.

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Abstract: In this Paper the effect of uncertainty in processing time was studied. Total processing time is randomly increased to some percentage, of standard test problems and variation of makespan is computed with CDS insertion method. Various situations were considered where one of the machines started slowing down, two machines slowing down, One old machine replaced with a new machine and one old machine is replaced with another old machine.

Uncertainty was incorporated by changing the processing time randomly within a limit for a machine and results were studied. Sub grouping of small processes was done and tested as depicted in the case studies.

Index Terms - Scheduling, Uncertainty, Sub grouping, Breakdown, Makespan

Introduction

Though the schedule is prepared and followed in the organization . In actual case there may be some unforeseen factors may arise. This factors has to be taken care of without much disturbance to the solution. The success of any industrial sector will depend on how efficiently it generates value by dynamically optimizing deployment of its supply chain resources. Among the challenges for the dynamic optimization of the entire supply chain enterprises are the rigorous but tractable optimization of process operations and the efficiently integration of different decision-making stages as well as the consideration of uncertainty and risk factors. Uncertainty may appear in all the different levels of the industry from the detailed process description to multisite manufacturing. Therefore, the successful utilization of process models relies heavily on the ability to handle system variability. During execution, the schedule may be subjected to considerable uncertainty that lead to numerous schedule disruptions. The uncertainty may stem from a number of possible sources, activities may take more or less time than originally estimated, resources may become temporarily unavailable, material may arrive behind schedule, ready times and due dates may have to be changed, new activities may have to be incorporated or some activities are dropped, drastic environment may cause delays. A disrupted schedule incurs higher costs due to missed due dates and deadlines, resource idleness, higher work-in-process inventory. Due to missed due dates and deadlines , resource idleness, higher work in process inventory the cost may arise .So a disrupted schedule may incur higher costs.

Literature Review

When designing a scheduling system, uncertainties need to be taken into account, since, as time goes by, production schedules become inaccurate or infeasible and eventually a new schedule will be needed.

Ketrina,*et.al* (2013) considered flow shop layouts that have seldom been studied in the rescheduling literature .They have generated and employed three types of disruption that interrupt the original schedules simultaneously. They have developed rescheduling algorithms accomplish the twofold objective of establishing a standard framework on the one hand, and proposing rescheduling methods that seek a good trade-off between schedule quality and stability on the other, Zhenhao Xu, Xingsheng Gu (2006) proposed a hybrid algorithm combined with the Immune algorithm with the Branch and Bound method for solving the fuzzy scheduling for flow shop problems with uncertain processing time, which can avoid the blind search of the Immune Algorithm. Aytug Haldun *et.al* (2005) have reviewed the literature on executing production schedules in the presence of unforeseen disruptions on the shop floor. They have discussed a number of issues related to problem formulation, and discussed the functions of the production schedule in the organization and provide a taxonomy of the different types of uncertainty faced by scheduling algorithms. J. Balasubramanian and I. E. Grossmann, (2004), considered the problem of scheduling under demand uncertainty of a multiproduct batch plant represented through a state-task network.. They have presented a multistage stochastic mixed integer linear programming (MILP) model, where in certain decisions are made irrespective of the realization of the uncertain parameters and some decisions are made upon realization of the uncertainty. Kamrad B and ORD Keith (2005), adopted a real options framework and developed a production control model that jointly incorporates process and market uncertainties. In this model, they have defined process uncertainty by random fluctuations in the outputs' yield and market risk through demand uncertainty for the output. Janak, S.L, *et.al* (2006), considered the problem of scheduling under uncertainty where the uncertain problem parameters can be described by a known probability distribution function. They have proposed a new approach to address the scheduling under uncertainty problem based on a robust optimization methodology, which when applied to mixed-integer (MILP) problems produced robust solutions that are, in a sense, immune against uncertainties in both the coefficients and right-hand-side parameters of the inequality constraints. The approach can be applied to address the problem of production scheduling with uncertain processing times, market demands, and/or prices of products and raw materials. Zukui Li, Marianthi Ierapetritou (2008) reviewed the main methodologies that have been developed to address the problem of uncertainty in production scheduling and identified the main challenges in this area. The uncertainties in process scheduling are first analyzed, and the different mathematical approaches that exist to describe process uncertainties are classified.

Rodrigues *et al.*, (1996) also considered uncertain processing times and proposed a rolling-horizon approach which incorporates a look-ahead procedure to avoid possible violations of future due dates. Wein and Ou (1991) stated that there are two kinds of models in production scheduling research. Deterministic models address the problems of jobs with processing times that are known at the time when decision-makers schedule jobs. Stochastic scheduling is the second approach in scheduling under uncertainty. It takes into account the uncertainty information at the original scheduling stage and its objective is to create optimal and reliable schedules in the presence of uncertainty. Dorn *et.al* (1994) stated that Majority of current scheduling research focuses on resource oriented uncertainty i.e. the variations in processing times, mean time between failure and mean time for repair. Uncertainty in a manufacturing situation is a complex phenomenon. Variability in processing speed has a different impact on the situation if the variation occurs early in the day or close to the end of a shift. Uncertainty that affects yield is more important after a few operations when value has been added and replacing the scrapped material in time to meet a due date is difficult, as opposed to yield variation in the very first operation. Lin *et al*., (2004) proposed a robust optimization method to address the problem of scheduling with uncertain processing times, market demands, or prices.

Vin and Ierapetritou, (2001) addressed the problem of quantifying the schedule robustness under demand uncertainty, introduced several metrics to evaluate the robustness of a schedule and proposed a multiperiod programming model using extreme points of the demand range as scenarios to improve the schedule performance of batch plants under demand uncertainty. Willy Herroelen and Roel Leus (2005) reviewed the fundamental approaches for scheduling under uncertainty: reactive scheduling, stochastic project scheduling, fuzzy project scheduling, robust (proactive) scheduling and sensitivity analysis and discussed the potentials of these approaches for scheduling under uncertainty projects with deterministic network evolution structure .Janak Stacy .L *et al* (2007), modeled the medium-term production scheduling of a multipurpose, multiproduct industrial batch plant by decomposition of the whole scheduling period into successive short horizons of a few days. Then, a novel continuous-time formulation for short-term scheduling of batch processes with multiple intermediate due dates is applied to each short horizon selected, leading to a large-scale mixed-integer linear programming (MILP) problem. J. Balasubramanian and I. E. Grossmann (2003) stated that the prevalent approach to the treatment of processing time uncertainties in production scheduling problems is through the use of probabilistic models. Apart from requiring detailed information about probability distribution functions, this approach also has the drawback that the computational expense of solving these models is very high. The unforeseen disturbances that affect the normal operations of real-life manufacturing settings have been classified into two large categories by Cowling and Johansson Anna Bonfill*et.al*(2005), addressed robustness in scheduling batch process with uncertain operations time. The uncertainty present in any process environment and related not only to variable market demand but also to operational disturbances is usually unavoidable, and therefore, poor performance may be attained with the execution of deterministic optimal schedule. Sanmarti *et al.,* (1997) presented a different approach for the scheduling of production and maintenance tasks in multipurpose batch plants in the face of equipment failure uncertainty. They computed a reliability index for each unit and for each scheduled task and formulated a nonconvex Mixed Integer Non Linear Programming model to maximize the overall schedule reliability.. Vin and Ierapetritou, (2001) addressed the problem of quantifying the schedule robustness under demand uncertainty, introduced several metrics to evaluate the robustness of a schedule and proposed a multiperiod programming model using extreme points of the demand range as scenarios to improve the schedule performance of batch plants under demand uncertainty.

Jia and Ierapetritou, (2004) proposed a multi-objective robust optimization model to deal with the problem of uncertainty in scheduling considering the makespan, model robustness and solution robustness. Normal Boundary Intersection technique was utilized to solve the multi-objective model and successfully produce Pareto-optimal surface that captures the trade-off among different objectives in the face of uncertainty. The schedules obtained by solving this multi objective optimization problem include robust assignments that can accommodate demand uncertainty.

Uncertainty description

In today’s competitive environment, the impact of uncertainties can no longer be ignored. Effective management of production uncertainties is becoming critical in the era of time-based competition. For example, if existing parts are scheduled without considering possible machine breakdowns, the planned commitment on order delivery will be seriously violated. The consideration of uncertainties in scheduling, however, has been proved to be very difficult because of the combinatorial nature of discrete optimization compounded by the presence of uncertain factors. The different approaches to deal with uncertainty in a scheduling environment where the evolution structure of the precedence network is deterministic are reactive scheduling, stochastic scheduling, scheduling under fuzziness, proactive (robust) scheduling, and sensitivity analysis. In order to avoid the difficulties of uncertainties in scheduling, an intuitive practice is to replace all random variables by their means, consequently converting the problem into a deterministic one. Previous deterministic methods can then be used to solve the converted problem. The performance of this method referred to as mean method.

The process industry is mostly representative of mass production repetitive manufacturing .The process industry has several specifics compared with the discrete industry .These specifics make process manufacturing complex and uncertain. The complexity of the production process arises primarily from the required linking of various sub processes, each of which affects the quality of the final product. The uncertainty of the process industry is expressed above all in product quality. It is desirable to achieve high and uniform product quality in every industrial process plant, but the non uniformity of the quality of basic raw materials, deviations in process parameters, failures of technological equipment, outages in energy supply, and often also combinations of various indeterminate reasons render any prediction of the level of both quality and production rate a risky business.

Scheduled activities are subjected to different sources of Uncertainties which may lead to numerous schedule disruptions. Different Methodologies to address the uncertainties in process scheduling problems, Robust Optimization based Preventive Scheduling Strategy aims at generating a robust preventive schedule to handle the possible parameter perturbations, Parametric Programming based Reactive Scheduling aims at responsive schedule regeneration or updating upon the happening of disruptive events.

Uncertainty in Scheduling

A flexible schedule is an incomplete schedule where decisions have still to be made. Constraints are associated with a flexible schedule to restrict the set of complete schedules that can be derived from it. A conditional schedule is a schedule in which distinct alternative subsets of partially ordered activities can be modeled. A predictive schedule is a schedule that is generated before the end of its execution. Predictive schedules are to be modified to adapt them to online situations which are not known beforehand. A predictive schedule is said to be robust if the quality of the eventually executed schedule is close to the quality of the predictive schedule. A predictive schedule is said to be stable if the decisions made in the eventually executed schedule are close to the decisions made in the predictive schedule. An adaptive scheduling system is a system that is able to generate a new executable schedule whenever the currently executing schedule is no longer executable.

Real time manufacturing systems exhibits a considerable amount of changes during their processing. There are two approaches in scheduling are the deterministic or static machine scheduling which assumes that all parameters that define the problem instance are unchangeable and known in advance and stochastic or dynamic scheduling is much more difficult but more general and realistic. Except of the static elements, another class of factors, defining the robustness of the schedule in terms of the real life events like machine breakdowns or human errors, is included.

It is assumed that the disruptions is described in the form of probability distribution and therefore three additional aspects have to be considered in development of any dynamic schedule like description of various types of disruptions, the likelihood of their occurrence and their influence on the system. Dynamic model suits better for most of the real time examples however, in many cases; the knowledge about the processes is limited as it is impossible to collect enough information to develop a robust dynamic schedule. In Offline Scheduling all available jobs are scheduled at once for the entire Planning horizon. In Online Scheduling the jobs are scheduled at the times that are needed. Reactive Scheduling is a process to modify the created schedule during the manufacturing process to adapt change (uncertainty) in production environment such as disruptive event, rush order arrivals, order cancellations, machine breakdowns etc. For these types of uncertainties there are not enough information prior to the realization of uncertain parameters that will allow a protective action. Preventive Scheduling is a process to deal with parameter uncertainties like processing time, demand of products etc. For this type of scheduling, historical data and forecasting techniques can be used to derive information about the behavior of uncertain parameters in future in the form of range of parameters or stochastic distributions. In completely reactive scheduling no firm schedule is generated in advance and decisions are made locally in real-time.

Predictive-reactive scheduling is presented as a two step process. First, a predictive schedule representing the desired behavior of the shop floor over the time horizon considered is generated. This schedule is then modified during execution in response to unexpected disruptions. The schedule actually executed on the shop floor after these modifications is called the realized schedule. The two main questions are when to initiate a rescheduling action and what that rescheduling action should be. Reactive scheduling, which is also called rescheduling, takes place when the schedule is implemented based on up-to-date information regarding the state of the system. It requires the modification of the existing schedule during the manufacturing process to adapt to changes (uncertainty) such as rush order arrivals, order cancellations or machine breakdowns. For this type of uncertainty there is not enough information prior to realization of the uncertain parameters that will allow a protective action, so almost all the methods in the literature aim to resolve a rescheduling problem once the disruptive events occur. The reactive scheduling actions are based on various underlying strategies. It can rely on simple techniques or heuristic rules to seek a quick schedule consistency restoration. Example of such a simple control rule is the well-known right shift rule Sadeh *et al.*, (1993). This rule will move forward in time all the activities that are affected by the schedule breakdown because they were executing on the resource(s) causing the breakage or because of the precedence relations. This strategy sometimes lead to poor results as it does not re-sequence activities. Another approach of reactive scheduling action is a full scheduling pass of that part of the job that remains to be executed at the time the reaction is initiated. This approach is referred to as full scheduling and uses deterministic performance measure like the new make span. Stochastic scheduling aims at scheduling the activities with uncertain durations in order to minimize the expected project duration subject to zero lag finish start precedence constraints and renewable resource constraints.

The process of modifying an existing production schedule in response to disruptions or other changes is commonly known as Rescheduling. In a static scheduling environment, there is a finite set of jobs to be scheduled, whereas in a dynamic environment jobs arrive on a continuous basis. Moreover, a static environment can be broken down into a deterministic environment, where all system parameters are exactly known and there is no uncertainty for the future, and a stochastic environment, where there is a finite set of jobs, but some variables are uncertain such as the case in which the processing times of tasks are modeled as random variables. In dynamic rescheduling environments, jobs arrive continuously over time. Similarly, the existing rescheduling strategies are classified into three main categories: dynamic, robust and predictive-reactive.

Uncertainty in demand forecast is usually the largest source of uncertainty. All production plans rely on a demand forecast or a demand plan as an input. A demand forecast extends over a multi-period planning horizon and represents the firm's best guess at the future demand. The forecast is based on a combination of inputs, which depend on the context. These inputs include a projection of historical demand data, as might be done by a statistical forecasting package; advanced orders in contexts where at least some of the production is make-to-order; a corporate demand plan for firms that operate with a sales and operations planning process; any customer forecasts that the customer is willing to share with the firm; and market intelligence, often in the form of expert judgments. As a firm gets more and better information about future demand, it updates the forecast. Indeed, in most planning systems, there is regular cycle in which the forecasts are moved forward and revised; for instance, at the start of each week, a new forecast for demand over the next thirteen weeks is released. The new forecast might reflect information inferred from the observed demand since the last forecast update, any changes to customer orders or forecasts, as well as any changes on the market outlook. Forecasts are never perfect, and the actual demand realization will differ from the forecast, resulting in a forecast error. To address the uncertainty due to forecasts, we need to characterize the forecast errors. Typically we will view the forecast errors as random variables for which we will want to know (at least) the first two moments. It is important to recognize here that the forecast for a particular product is usually a vector of forecasts, which cover the planning horizon. That is, at any time t, for each product we have a forecast for future time periods t+i, for i = 1, … H, where H is the planning horizon. Thus, we have H forecasts; for instance if we have weekly time periods, then we have a one-week forecast, a two-week forecast and so on. We then need to characterize the errors for each type of forecast, as each forecast has a different impact on the production plan.

Uncertainty in external supply process is associated with the external supply process. A production plan results in orders placed on outside suppliers. Furthermore, the production plan has expectations on the fulfillment of these orders. That is, a plan might initiate an order for ten steel plates of a certain dimension and grade, and then expect that these plates will arrive and be available for processing according to a stated lead time of, say, eight weeks. Nevertheless, there can be uncertainty in the delivery date due to uncertainty and capacity constraints in the supplier's manufacturing and distribution processes; for instance, the order might not arrive until ten weeks due to a work stoppage or delays attributable to the weather. Furthermore, in many contexts there can be uncertainty in the amount of the delivery. For instance, a supplier might be permitted by contract to deliver plus or minus 10% of the amount ordered; in other contexts, the buyer might reject some portion of the delivery due to quality considerations. To model this uncertainty, one needs to characterize the uncertainty in the replenishment lead times and in the replenishment quantities.

Uncertainty in internal supply process similar to the uncertainty in the external supply process. A production plan results in work or job orders placed on the internal manufacturing, transportation and supply processes. Furthermore, the production plan has expectations on how these processes will perform. That is, a plan might set the number of wafer starts into a semiconductor fabrication facility with expectations on both the yield from these wafers and the flow time or process duration for these wafers within the fabrication facility. Again, there is uncertainty on both accounts. The actual flow or completion time will deviate from the expectation depending upon the work-in-process in the shop, the equipment availability and the dispatch rules; the wafer yield is inherently random and depends on numerous process factors and conditions. Again, one needs to characterize the uncertainty in the flow or process lead times and in the yield quantities for each process step. Uncertainty: It refers to measuring the degree of differences between the models and the respective real systems' values or between the estimation of variables and their true values. The uncertainty can be caused by the errors associated with the model itself and the uncertainties of the model inputs.

To include the description of uncertain parameters within the optimization model of the planning and scheduling problem, different methods have been used. Bounded form, in many cases, there is not enough information in order to develop an accurate description of the probability distribution that characterize the uncertain parameters, but only error bounds can be obtained. In this case interval mathematics can be used for uncertainty estimation, as this method does not require information about the type of uncertainty in the parameters. This is the typical and readily applicable method to describe the uncertain parameters. The bounds represent the ranges of all possible realizations of the uncertain parameters. The upper and lower bounds can be determined with the analysis of the historical data, customer's orders and market indicators. Probability description: This is a common approach for the treatment of uncertainties when information about the behavior of uncertainty is available since it requires the use of probabilistic models to describe the uncertain parameters. In the probabilistic approach, uncertainties are characterized by the probabilities associated with events. The probability of an event can be interpreted in terms of the frequency of occurrence of that event. When a larger number of samples or experiments are considered, the probability of an event is defined as the ratio of the number of times the event occurs to the total number of samples or experiments. The uncertainty is modeled using either discrete probability distributions or the discretizations of continuous probability distribution function. Uncertainties such as equipment breakdown, failure of process operations are generally described with discrete parameters. In many industrial processes machine failures continuously affect the planned activities. Preventive maintenance may reduce the breakdown rate, but it is almost impossible to eradicate this type of disruption from the system. Similarly, other parameters such as material availability and market demand are highly likely to undergo modifications and, hence, it is crucial to react rapidly and produce new schedules that take into account the new system variables. Three types of events that will disrupt the predictive schedules are generated for this work: Machine breakdowns, new job arrival and job ready time variations.

Introduction of Sub grouping

Many a times it is found that the organizations have limited machines to produce the products. The jobs to be processed arrive with diversities in nature, so the processing time and machines required for the particular job is different. So sometimes this does happen that a particular group of machines are catering to majority of the jobs along with other machines. For example costlier machines have been utilized many a times to optimize its utility and achieve its breakeven. There are some jobs which do not need these special machines. Also there are some machines in the organization without having any spares. The schedulers are always in the need for rescheduling on the arrival of the new jobs. It is found that many a jobs have to be processed in the same machine and rarely with some specific machines. So these machines can be grouped in order of the timing and more utilized or less utilized, which gives an idea of sub grouping of the machines.

Sub grouping of Processes

In general the organization is divided into number of shops. Each shop is to handle a particular type of process. Each may consist of smaller processes. A group of common machines are there which are used for a number of smaller processes. For example Process industries like paint, fabrication etc. As the small processes are to be followed by a number of processes after preceding activities so they have to be in the waitlist according to the constraints like demand, due date delivery schedules etc. Sometimes rush orders compels to stop the low prioritized orders. By the way some orders has to be stopped in different steps of the process to complete the rush order. Sometimes the orders are so random in nature example that the other process are distributed to meet the priority of the random order. The total scheduling of the shop has to be altered to cope up with the random order. The best way to process in parallel all the activities in small batches of different size. This can be solved using a number counters of the same sub process subject to breakdown analysis. If also there are multiple machines of same nature, then the capacity and quality difference creates the reschedule of the rush order. Breakdown is also constraint to increase the load on similar machines and the research is to be done for the processes involving these machines. If it can arrange according to the number of machines in the sub process in a group, the scheduling will be with the sub group instead of all the machines individually, though the processing of different process will be different but a separate schedule is to be prepared.

The following are the inputs to the problem of design of the schedule for small group of process.

1.Manufacturing process consists of different machines and interconnecting sections, operating protocols like the materials (resources) may occupy a block section at a time and they can't move to another block section before the schedule departure time , Machine running and material movement follows a fixed itinerary as given in the schedule , Maintenance requirements of machines i.e. minimum time required for major and minor maintenance at block sections nominated for the purpose, Machine downtime requirements, that is the minimum rest period to be provided to the machines. The Scheduling is to be designed such that, the robustness of the schedule is maximized, the deployment of resources is minimized, the deployment of manpower is minimized.

Data Analysis

The effect of uncertainty in processing time on makespan using CDS Insertion method.

The total processing time is randomly increased to some percentage, of the standard test problems and the variation of makespan is computed with CDS insertion method. It is illustrated in table.1 in this case we have introduced a percentage change in processing time from 5-30% in an interval of 2.5%.

Table.1Variation in makespan due to a percentage change in processing time

Standard test problem	Nxm	(A) 0-5% change in processing time	(B) 0-10% change in processing time	(C) 0-15% change in processing time	(D) 0-20% change in processing time	(E) 0-25% change in processing time	(F) 0-30% change in processing time
abz7	15x20	0.806	1.2195	1.633	2.815	3.991	5.692
ft06	6x6	0	0.8329	1.886	3.306	4.83	6.944
la05	10x5	0.217	0.5624	1.606	2.271	4.688	4.837
la07	15x5	0.619	1.3738	2.852	3.606	5.596	7.454
la12	20x5	0.451	0.8888	1.769	2.112	3.018	3.075
la17	10x10	0.216	0.8407	1.228	2.38	3.92	4.667
la22	15x10	1.182	1.4502	1.386	2.147	2.852	4.645
la31	30x10	0.544	0.729	1.157	2.232	2.824	4.902
la39	15x15	0.386	1.3183	1.264	2.636	3.905	6.171
swv02	20x10	0.96	1.4215	2.57	3.95	5.73	8.254
swv07	20x15	0.521	0.839	1.249	2.088	3.63	4.908
swv17	50x10	0.392	0.7248	1.059	1.958	2.795	4.364
yn3	20x20	0.988	1.7739	2.47	4.039	4.985	6.836

In these tables one example of every size is considered. The variation in makespan due to a percentage change in processing time for the rest of the standard test problems are depicted in the Appendix - 6From the table.1 it is observed that the 5% -30% variation of uncertainty results in variation in makespan within 3%.So it is concluded that a small form of uncertainty can be handled with fewer disturbances in delivery dates and thus not affecting the profit.

Table.2 percentage change in processing time and total number of changes in processing time in column A ,B,C,D,E and F.

	Percentage change in processing time	Total No. of changes in processing time
A	0-5%	5
B	0-10%	10
C	0-15%	15
D	0-20%	20
E	0-25%	25
F	0-30%	30

The graph is between percentage variation in the processing time in the abscissa and percentage error in with respect to makespan in the ordinate. The percentage variation varies from 5% to 30% in a particular machine. When the percentage of variation in processing time increases the error in with respect to makespan also increases. In initial percentage (upto 15%) it is less and the rate is more afterwards. In general upto 12.5% variation in processing time the error in makespan is within 1% which implies less amount defer in scheduling i.e. 1% we can plan. The overall error is calculated and shown in figure.1

Fig.1 Error due to uncertainty 6x6 problem for range 1to 10.

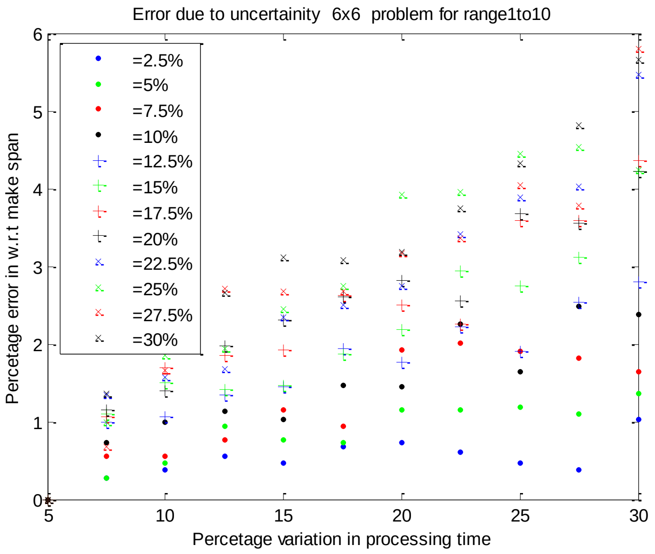
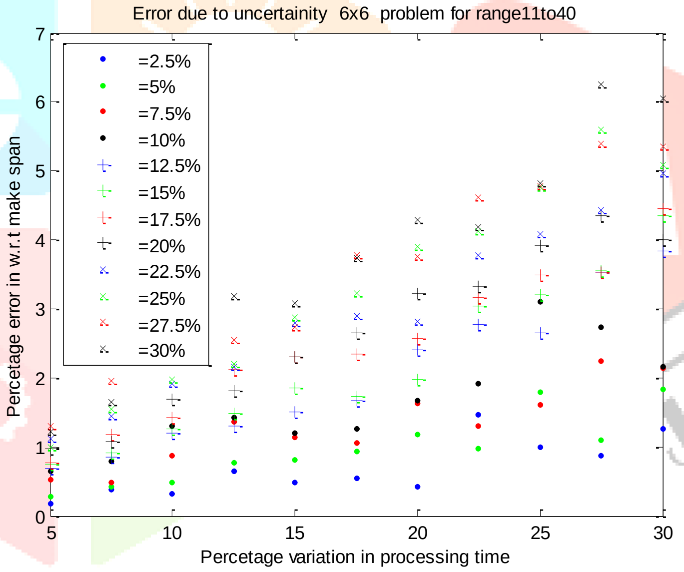


Fig.2 Error due to uncertainty 6x6 problem for range 11to 40.



Similarly another situation is considered where one of the machine started slowing down, we incorporate the uncertainty problem by changing the processing time randomly within a limit for a particular machine and the result is shown in table.3

Table.3 variation in makespan for one machine slowing down

Standard test problems	Xr	(A) 0-5% variation in processing time	(B) 0-10% variation in processing time	(C) 0-15% variation in processing time	(D) 0-20% variation in processing time	(E) 0-25% variation in processing time	(F) 0-30% variation in processing time
abz7	7.0000	0.3825	0.7896	0.7633	1.2625	1.5876	2.0244
ft06	6.0000	0	0.8834	2.1639	3.6662	3.1025	4.5334
la05	3.0000	0.9703	1.9911	2.5046	3.3547	5.5679	6.4007
la07	2.0000	2.4911	3.2488	5.0870	6.5404	8.0613	5.4433
la12	3.0000	0.9442	1.5975	2.2204	3.4057	3.5738	3.6552
la17	10.0000	0.7145	0.6282	1.2801	1.9414	1.7822	1.7982
la22	8.0000	1.1255	1.1396	1.2206	1.8006	1.7823	2.8889
la31	4.0000	0.4999	0.8363	1.3479	1.8242	2.8535	3.1050
la39	4.0000	0.4649	0.8108	1.1797	1.4293	1.7703	2.2328
swv02	5.0000	0.8638	1.2411	2.1075	2.9553	4.1085	4.7576
swv07	9.0000	0.3087	0.7113	1.0187	1.1533	1.4648	1.5618
swv17	5.0000	1.4101	2.1187	2.6939	3.3948	4.2003	5.1053
yn3	12.0000	0.3547	0.6988	0.8131	1.0613	1.2711	1.3156

From the table it is found that when the numbers of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to run one old machine along with other machines. The situation for One old machine (slowing down) can be achieved with a little variation in delivery due dates.

The graph is between percentage variation in the processing time in the abscissa and percentage error in with respect to makespan in the ordinate. The percentage variation varies from 5% to 30% in one old machine. When the percentage of variation in processing time increases the error in with respect to makespan also increases. In initial percentage (upto 15%) it is less and the rate is more afterwards. In general upto 12.5% variation in processing time the error in makespan is within 1% which implies less amount defer in scheduling i.e. 1% we can plan. The overall error is calculated and shown in figure.3.

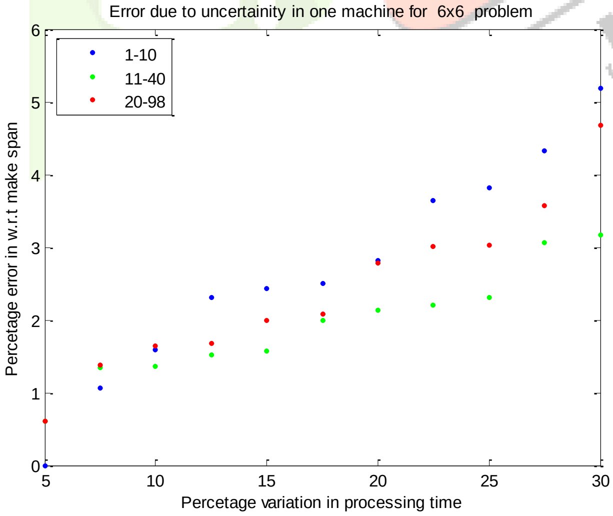


Fig.3 Error due to uncertainty in one machine for 6x6 problem

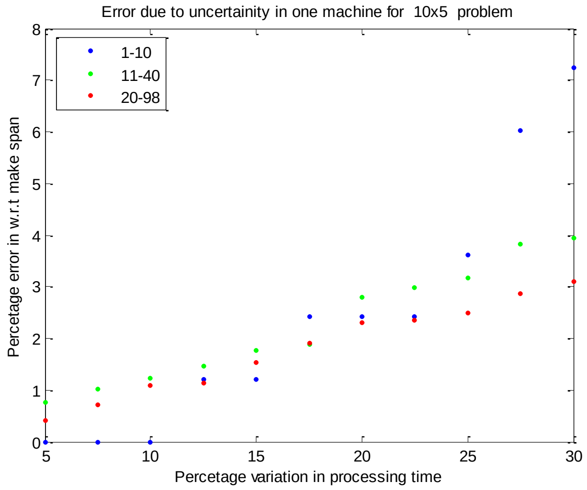


Fig.4 Error due to uncertainty in one machine for 10x5 problem

Similarly another situation also tested for two machines slowing down. Result shown in Table.4 variation in makespan for two machines slowing down

Table.4 variation in makespan for two machines slowing down

Standard test problems	Xr	(A) 0-5% variation in processing time	(B) 0-10% variation in processing time	(C) 0-15% variation in processing time	(D) 0-20% variation in processing time	(E) 0-25% variation in processing time	(F) 0-30% variation in processing time
abz7	7.00	0.76	0.84	1.04	1.29	1.95	2.89
ft06	15.00	0.52	0.57	1.12	1.34	1.83	2.32
la05	2.00	1.34	2.31	4.27	5.14	6.04	7.14
la07	2.00	1.64	2.93	4.55	5.17	6.96	8.28
la12	5.00	1.43	3.07	3.46	3.83	5.04	7.39
la17	2.00	1.47	2.41	2.76	3.05	4.18	5.40
la22	4.00	0.94	1.13	1.74	2.35	2.98	3.95
la31	2.00	1.27	2.30	2.06	2.87	3.91	4.68
la39	9.00	0.63	0.85	1.27	1.76	2.28	2.16
swv02	1.00	1.12	2.32	3.08	4.35	6.00	6.84
swv07	9.00	0.56	1.08	1.39	1.88	2.15	2.85
swv17	2.00	1.79	3.12	3.85	4.91	5.95	7.26
yn3	3.00	0.80	1.15	1.31	1.83	1.90	2.49

From the table.4 it is found that when the number of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to two old machine can be achieved with a little variation in delivery due dates.The graph is between percentage variation in the processing time in the abscissa and percentage error in with respect to makespan in the ordinate. The percentage variation varies from 5% to 30% in two old machines. When the percentage of variation in processing time increases the error in with respect to makespan also increases. In initial percentage (upto 15%) it is less and the rate is more afterwards. In general upto 12.5% variation in processing time the error in makespan is within 1% which implies less amount defer in scheduling i.e. 1% we can plan. The overall error is calculated and shown in figure 5

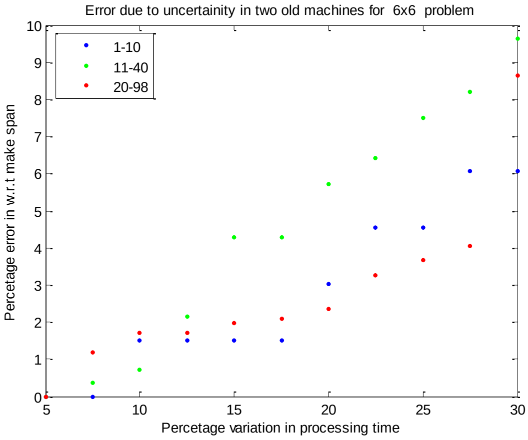


Fig5 Error due to uncertainty in two old machines for 6x6 problem

Similarly another situation one old machine replaced with a new machine and one old machine is replaced by another old machine. Results are shown in table.5

Table 5 variation in makespan due to one old machine replaced with a new machine and one old machine is replaced by another old machine.

Standard test problems	Nxm	xr	0-5% variation in processing time	0-10% variation in processing time	0-15% variation in processing time	0-20% variation in processing time	0-25% variation in processing time	0-30% variation in processing time
abz7	15x20	15.00	0.56	0.90	1.03	1.10	1.21	1.69
ft06	6x6	2.00	0.00	1.32	2.26	3.13	4.47	3.81
la05	10x5	6.00	0.89	1.63	2.48	3.18	4.35	5.91
la07	15x5	4.00	1.95	3.81	5.26	5.13	6.01	7.53
la12	20x5	4.00	1.07	1.43	2.41	2.63	3.13	4.12
la17	10x10	2.00	0.76	1.13	1.06	1.41	1.78	1.89
la22	15x10	5.00	1.61	1.33	2.06	2.50	2.76	2.26
la31	30x10	4.00	0.80	0.84	1.02	1.56	2.40	2.87
la39	15x15	7.00	0.40	1.09	1.18	1.16	0.99	1.53
swv02	20x10	6.00	0.70	1.05	2.33	2.57	4.30	4.29
swv07	20x15	16.00	0.46	0.74	0.84	0.89	0.76	1.20
swv17	50x10	8.00	1.51	1.91	2.62	3.18	4.13	4.11
yn3	20x20	17.00	0.39	0.56	0.52	0.62	0.78	1.03

From the table5 it is found that when the numbers of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to run a new machine with a old machine can be achieved with a little variation in delivery due dates. The graph is between percentage variation in the processing time in the abscissa and percentage error in with respect to makespan in the ordinate. The percentage variation varies from 5% to 30% in one new machine and one old machine. When the percentage of variation in processing time increases the error in with respect to makespan also increases. In initial percentage (upto 15%) it is less and the rate is more afterwards. In general upto 12.5% variation in processing time the error in makespan is within 1% which implies less amount differ in scheduling i.e. 1% we can plan. The overall error is calculated and shown in figure 6

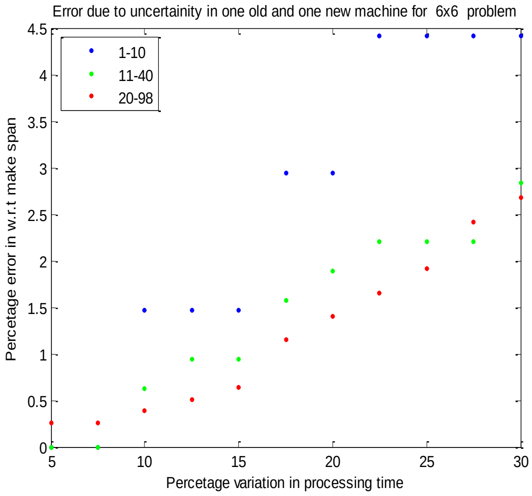


Fig.6 Error due to uncertainty in one old and one new machines for 6x6 problem

In order to know the effect of uncertainty in real cases two organizations are visited. One is a Chemical industry nearby which produces Hydrochloric acid, Sodium hydroxide, Chlorine and sodium hypochlorite as it finished products. Similarly a second organization which manufactures different sizes of papers was also visited. Out of the total process we have considered some units of the process Brief description of the processes of these two organizations are given in the Appendix-2

Case Study 1

For our purpose the pre processing and post processing part is only taken into account. The plant produces NaOH, HCl, HOCl and chlorine. The process can be depicted as a 5 job 9 machine problem. There are 3 nos. of machine1 (Brine Saturator)[M1], 1 no. of makeup water addition chamber[M2],1 no. of brine purification unit[M3],Brine filtration unit[M4],one electrolysis chamber[M5],As the finished product we get NaOH from machine6[M6] and From machine 7 [M7]we get HCl ,HOCl and Cl and packaging is done in machine8[M8] and machine 9[M].

Four types of uncertainty are introduced into the process as follows, for a particular job the machine has been randomly changed either due to defect or breakdown and the effect of change in processing time on makespan is calculated by simulation. For a particular machine the processing speed is increased and the effect on processing time is calculated. For any two machines the processing time is increased and the effect on makespan is studied. One new machine is introduced in the place of an older machine and one old machine is replaced by another old machine. The processing time in the new machine increases and the processing time in the old machine decreases. The effect on the makespan is studied.

For the case study 2 a nearby paper manufacturing plant has been selected.

The process can be depicted as a 17 jobs 11 machines problem. The final product i.e. paper is produced with a variation from 60 GSM to 300 GSM grades. The volume of production varies as per the demand of the customers in the required GSM grade. There are five numbers of chip screening machine[M1], two nos. of re chipper machine [M2], one no. of RDH digester[M3],One Fibreline [M4], One disc Knotter unit[M5],One BSW[M6],one Screening machine [M7], two numbers of DP machines[M8], Oxygen delignification[M9],Post Oxygen washing[M10], paper cutting machine[M11],four nos. of packaging machine[M12].For our purpose we have taken small group of process as one sub group like [M1,M2,M3,]is considered as one sub group, [M4,M5,M6,M7] as another subgroup and [M8,M9,M10,M11] as another sub group. The endeavor is to do optimization of the process by the strategic scheduling of small group of process in the presence of uncertainty. Four types of uncertainty are introduced into the process as follows, for a particular job the machine has been randomly changed either due to defect or breakdown and the effect of change in processing time on makespan is calculated by simulation. For a particular machine the processing speed is increased and the effect on processing time is calculated. For any two machines the processing time is increased and the effect on makespan is studied. One new machine is introduced in the place of an older machine and one old machine is replaced by another old machine. The processing time in the new machine increases and the processing time in the old machine decreases. The effect on the makespan is studied.

Sub grouping and Case Study

Sub grouping of Processes

In general the organization is divided into number of shops. Each shop is to handle a particular type of process. Each may consist of smaller processes. A group of common machines are there which are used for a number of smaller processes. For example Process industries like paint, fabrication etc. As the small processes are to be followed by a number of processes after preceding activities so they have to be in the waitlist according to the constraints like demand, due date delivery schedules etc. Sometimes rush orders compels to stop the low prioritized orders. By the way some orders has to be stopped in different steps of the process to complete the rush order. Sometimes the orders are so random in nature example that the other process are distributed to meet the priority of the random order. The total scheduling of the shop has to be altered to cope up with the random order. The best way to process in parallel all the activities in small batches of different size. This can be solved using a number counters of the same sub process subject to breakdown analysis. If also there are multiple machines of same nature, then the capacity and quality difference creates the reschedule of the rush order. Breakdown is also constraint to increase the load on similar machines and the research is to be done for the processes involving these machines. If it can arrange according to the number of machines in the sub process in a group, the scheduling will be with the sub group instead of all the machines individually, though the processing of different process will be different but a separate schedule is to be prepared.

In some organization the jobs to be taken are such that they have to pass through a combination of different groups of machines. Such that a particular group has to be dependent for all the jobs where other groups have substitute of parallel units, such that multiple jobs can be processed time to time. Keeping this in mind we studied the effect by sub grouping the large number of jobs to small groups as shown in table.6 The effect on makespan is depicted in table.7

Table.6 Sub grouping of Jobs.

	10 jobs	2+3+2+3
	15jobs	5+5+3+2
	20 jobs	4+4+4+4+2+2+
	30 jobs	5+5+5+2+3+4+6
	50jobs	6+6+6+6+6+5+5+5+5

Table.7 Affect on makespan after sub grouping.(Comparison with Insertion method results)

Standard Test Problems	SIZE (nxm)	Result of insertion Method	Result of Sub grouping method	Error (results of subgrouping method – results of insertion method)/insertionmethod results*100
abz7	15x20	943	955	1.256544503
ft06	6x6	62	NA	NA
la05	10x5	666	677	1.624815362
la07	15x5	988	1003	1.49551346
la12	20x5	1209	1217	0.65735415
la17	10x10	1009	1009	0
la22	15x10	1289	1343	4.020848846
la31	30x10	2217	2277	2.635046113
la39	15x15	1773	1808	1.935840708
swv02	20x10	1565	1633	4.164115126
swv07	20x15	1962	1988	1.307847082
swv17	50x10	3298	3319	0.632720699
yn3	20x20	1285	1282	-0.23400936

Using Sub grouping technique for Case study 1

The process can be depicted as a 5 job 9 machine problem. There are 3 nos. of machine1 (Brine Saturator)[M1], 1 no. of makeup water addition chamber[M2],1 no. of brine purification unit[M3],Brine filtration unit[M4],one electrolysis chamber[M5],As the finished product we get NaOH from machine6[M6] and From machine 7 [M7]we get HCl ,HOCl and Cl and packaging is done in machine8[M8] and machine 9[M].For our purpose we have we have considered the machines [M3, M4 and M5] as one small group of process or a sub group. The endeavor is to do the optimization of the process by the strategic scheduling of small group of process.

Using Sub grouping technique for Case study 2

The process can be depicted as a 17 jobs 11 machines problem.The final product i.e. paper is produced with a variation from 60 GSM to 300 GSM grades. The volume of production varies as per the demand of the customers in the required GSM grade. There are five numbers of chip screening machine[M1], two nos. of re chipper machine [M2], one no. of RDH digester[M3],One Fibre line [M4], One disc Knotter unit[M5],One BSW[M6],one Screening machine [M7], two numbers of DP machines[M8], Oxygen delignification[M9],Post Oxygen washing[M10], paper cutting machine[M11],four nos. of packaging machine[M12].For our purpose we have taken small group of process as one sub group like [M1,M2,M3,]is considered as one sub group, [M4,M5,M6,M7] as another subgroup and [M8,M9,M10,M11] as another sub group. The endeavor is to do optimization of the process by the strategic scheduling of small group of process in the presence of uncertainty. Four types of uncertainty are introduced into the process as follows, for a particular job the machine has been randomly changed either due to defect or breakdown and the effect of change in processing time on makespan is calculated by simulation. For a particular machine the processing speed is increased and the effect on processing time is calculated. For any two machines the processing time is increased and the effect on makespan is studied. One new machine is introduced in the place of an older machine and one old machine is replaced by another old machine. The processing time in the new machine increases and the processing time in the old machine decreases. The effect on the makespan is studied.

Findings and Conclusion

.The effect of uncertainty in processing time on makespan using CDS insertion method is studied. The total processing time is randomly increased to some percentage, of the standard test problems and the variation of makespan is computed with CDS insertion method. Similarly another situation is considered where one of the machines started slowing down, we incorporate the uncertainty problem by changing the processing time randomly within a limit for a particular machine. It is found that when the number of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to run a one old machine (slowing down) can be achieved with a little variation in delivery due dates. Similarly another situation also tested for two machines slowing down. It is found that when the numbers of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to two old machine can be achieved with a little variation in delivery due dates. Similarly another situation one old machine replaced with a new machine and one old machine is replaced by another old machine. It is found that when the number of machines are more the fluctuation is less and when the processing time is more the fluctuation is slightly more. So strategies should be devised to run a new machine with a old machine can be achieved with a little variation in delivery due dates. The sub grouping of small processes was done and tested as depicted in the case studies.

Findings

1. Uncertainty plays a vital role in scheduling process. There are different types of uncertainties affecting the scheduling process. In this work the total processing time is randomly increased to some percentage, of the standard test problems and the variation of makespan is computed with CDS insertion method. In this case we have introduced a percentage change in processing time from 5-30% in an interval of 2.5%.Similarly another situation is considered where one of the machine started slowing down, we incorporate the uncertainty problem by changing the processing time randomly within a limit for a particular machine. Another situation is also tested for two machines slowing down. Similarly another situation one old machine replaced with a new machine and one old machine is replaced by another old machine.

2.Many a times it is found that the organizations have limited machines to produce the products. The jobs to be processed arrive with diversities in nature, so the processing time and machines required for the particular job is different. So sometimes this does happen that a particular group of machines are catering to majority of the jobs along with other machines. For example costlier machines have been utilized many a times to optimize its utility and achieve its breakeven. There are some jobs which do not need these special machines. Also there are some machines in the organization without any having any spares. The schedulers are always in the need for rescheduling on the arrival of the new jobs. It is found that many a jobs have to be processed in the same machine and rarely with some specific machines. So these machines can be grouped in order of the timing and more utilized or less utilized, which gives an idea of sub grouping of the machines.

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APPENDIX -1

Variation in makespan due to a percentage change in processing time.

Standard test problem	Nxm	(A) 0-5% change in processing time	(B) 0-10% change in processing time	(C) 0-15% change in processing time	(D) 0-20% change in processing time	(E) 0-25% change in processing time	(F) 0-30% change in processing time
abz5	10x10	0.194	0.5184	1.33	2.248	3.562	5.773
abz6	10x10	0.194	0.5184	1.33	2.248	3.562	5.773
abz7	15x20	0.806	1.2195	1.633	2.815	3.991	5.692
abz8	15x20	0.246	0.6047	1.263	2.116	2.998	4.945
abz9	15x20	0.34	0.6074	1.306	1.601	2.705	4.375
ft06	6x6	0	0.8329	1.886	3.306	4.83	6.944
ft10	10x10	0.594	0.8815	1.834	3.166	4.49	5.641
ft20	20x5	0.316	0.8572	1.613	2.637	3.635	5.57
la01	10x5	0.37	1.3281	2.371	3.376	4.725	6.99
la02	10x5	0.319	0.7109	1.495	2.673	4.07	4.636
la03	10x5	0.46	0.8454	2.04	2.606	4.523	5.345
la04	10x5	0.332	0.8829	1.62	2.365	4.203	6.021
la05	10x5	0.217	0.5624	1.606	2.271	4.688	4.837
la06	15x5	0.228	0.8614	1.822	2.439	4.055	5.141
la07	15x5	0.619	1.3738	2.852	3.606	5.596	7.454
la08	15x5	0.41	1.0482	2.006	3.024	4.353	5.761
la09	15x5	1.084	1.3979	2.863	3.48	5.388	7.186
la10	15x5	0.341	0.8316	1.48	2.282	4.229	5.718
la11	20x5	0.296	0.7879	2.116	3.024	4.518	6.502
la12	20x5	0.451	0.8888	1.769	2.112	3.018	3.075
la13	20x5	0.305	0.827	1.518	2.546	3.668	4.957
la14	20x5	0.551	0.9367	1.424	2.649	4.42	5.471
la15	20x5	0.257	0.7502	1.889	3.017	4.228	5.808
la16	10x10	0.854	1.684	2.68	4.005	5.073	6.717
la17	10x10	0.216	0.8407	1.228	2.38	3.92	4.667
la18	10x10	1.005	1.5971	2.099	2.785	3.392	5.555
la19	10x10	1.526	1.5872	2.305	3.128	3.779	5.741
la20	10x10	0.26	0.9691	1.851	3.32	3.938	5.604
la21	15x10	0.61	0.9137	1.133	1.698	2.645	4.086
la22	15x10	1.182	1.4502	1.386	2.147	2.852	4.645
la23	15x10	1.316	1.4834	1.64	2.24	3.941	4.627
la24	15x10	0.46	1.5245	2.975	4.443	5.714	7.621
la25	15x10	0.308	0.8937	2.124	3.128	4.104	5.662
la26	20x10	0.554	1.0487	2.151	2.818	4.35	6.423
la27	20x10	0.31	0.7756	1.306	2.286	3.644	5.087
la28	20x10	0.272	1.0652	2.423	3.812	5.556	6.968
la29	20x10	0.513	1.101	2.247	3.311	4.875	5.828
la30	20x10	0.419	1.3353	2.459	3.694	4.436	6.526

la31	30x10	0.544	0.729	1.157	2.232	2.824	4.902
la32	30x10	0.744	1.4441	2.229	2.805	4.214	5.647
la33	30x10	0.233	0.7597	1.438	2.497	4.039	5.204
la34	30x10	0.604	1.4677	2.153	3.068	4.309	6.152
la35	30x10	1.424	2.354	3.349	4.621	5.32	7.254
la36	15x15	0.524	1.4306	2.473	3.587	4.338	7.05
la37	15x15	0.916	1.0945	1.101	1.474	2.454	3.713
la38	15x15	0.354	0.9467	1.233	1.739	2.771	4.656
la39	15x15	0.386	1.3183	1.264	2.636	3.905	6.171
la40	15x15	0.728	0.9426	1.555	1.749	3.261	4.216
orb01	10x10	0.233	1.7397	1.735	2.509	3.246	5.863
orb02	10x10	0.792	0.7546	0.937	1.858	3.082	4.99
orb03	10x10	0.386	0.9418	1.21	2.124	3.66	5.4
orb04	10x10	0.285	0.836	1.371	2.674	3.176	5.363
orb05	10x10	0.341	0.6485	1.061	1.707	2.797	4.54
orb06	10x10	0.286	0.7132	1.265	2.684	3.113	5.549
orb07	10x10	0.385	0.7634	1.276	1.86	3.305	5.243
orb08	10x10	0.289	0.7948	1.519	2.822	3.863	5.273
orb09	10x10	0.739	2.2992	3.144	4.582	5.428	7.817
orb10	10x10	0.257	0.7021	1.316	2.467	3.978	5.502
swv01	20x10	0.447	1.5096	2.747	4.011	5.58	7.404
swv02	20x10	0.96	1.4215	2.57	3.95	5.73	8.254
swv03	20x10	0.793	1.8452	1.791	2.79	4.202	6.206
swv04	20x10	1.027	1.5924	1.576	1.744	3.181	4.184
swv05	20x10	0.28	1.1291	1.65	2.394	3.859	5.704
swv06	20x15	0.56	1.2354	1.919	2.681	3.876	5.271
swv07	20x15	0.521	0.839	1.249	2.088	3.63	4.908
swv08	20x15	0.438	1.3914	2.327	2.768	5.206	6.513
swv09	20x15	0.484	1.4647	2.194	2.997	5.117	6.119
swv10	20x15	0.362	0.7991	1.445	2.377	3.493	5.258
swv11	50x10	0.341	0.7899	1.463	2.581	3.65	4.801
swv12	50x10	0.797	1.3248	2.059	3.125	4.62	6.632
swv13	50x10	0.504	1.1949	2.255	3.584	4.269	6.486
swv14	50x10	0.482	0.5903	1.82	2.82	4.311	5.672
swv15	50x10	0.366	0.7771	1.806	2.39	4.073	5.816
swv16	50x10	0.967	1.8396	2.367	3.394	4.481	5.512
swv17	50x10	0.392	0.7248	1.059	1.958	2.795	4.364
swv18	50x10	1.328	2.1877	3.402	4.721	5.568	7.455
swv19	50x10	0.54	1.7192	2.244	3.503	4.576	6.027
swv20	50x10	0.241	0.6102	1.364	2.061	3.45	4.482
yn1	20x20	0.385	0.8361	1.633	2.453	4.008	5.344
yn2	20x20	0.515	0.7058	1.131	1.821	3.126	4.753
yn3	20x20	0.988	1.7739	2.47	4.039	4.985	6.836
yn4	20x20	0.63	0.9916	1.659	2.786	3.988	5.572

APPENDIX-2

CASE STUDY 1

Brief description of the Process

Brine Saturation: For Brine Saturation NaCl is addedin the saturator. Makeup water is added to the saturator such that the brine solution is concentrated. Only one Brine saturator is provided and there is no standby saturator. Thatswhy when breakdown happens at the brine saturation section then the production is stopped for around 24 hours. Huge amount of loss is incurred due to the breakdown. Raw Salt (NaCl) contains many insoluble matters , which get settled at the bottom of the saturator . These insoluble's are removed periodically from the bottom of the saturator. The Salt (brine) Saturator is shutdown for one day in a month for maintenance purpose. Raw material Stock: There is always a10-15 days stock of NaCl that is around 2600 to 3500 tonnes is kept in the plant.
Brine Primary Purification: The Sludge and liquid effluent are removed i.e. chemicals are added to the brine stream to remove mainly Ca and Mg cations and SO_4 anions. Precipitates are collected in a settler and clarified brine is sent to the filtration chamber.
Brine Filtration : Brine stream is filtered to remove suspended solids as CaCO3, Mg(OH)2 &BaSO4. After filtration, brine is sent to the electrolyzer. Concentration of Ca and Mg is reduced to less than 20 ppb. The filtered brine is fed to the electrolyte cell after eliminating the 2% impurity. Some return brine from Reactor (Electrolyte cell) comes to the Saturator.
Chlorine gas treatment: Chlorine gas is cooled to reduce the water content , then it is sent to the mist eliminator to remove water droplets and NaCl traces. Drying - In this section the Chlorine water content is reduced to ppm. Drying takes place in packed towers using sulphuric acid (H_2SO_4) as drying media. Compression- The Chlorine gas pressure is increased to a suitable level for the downstream liquefaction unit. The dry compressed gas passes through a high efficiency demister for removal of all entrained acid before entering the chlorine condenser. Liquefaction: chlorine Liquefaction takes place in a chlorine liquefier where the chlorine gas is cooled and condenses. Liquid Chlorine is then sent to the storage. Liquefier works 24hr throughout the year. It doesn't have a standby unit. Once power failure happens it takes 4hrs to start the process.
Electrolyzer: In membrane cell technology the solutions surrounding each electron are separated by a membrane . The membrane is very selective and primarily allows the migration of sodium ions from anode chamber to the cathode chamber Saturated brine enters the anode compartment of the cell where Chlorine gas is liberated at the anode surface and the brine in the anode compartment is depleted. As a result of the electrochemical reaction taking place in the cathode chamber , H_2 generated at the cathode surface and the OH ions combine with Na^+ ions diffusing through membrane. The Overall Electrochemical Reaction 2NaCl + $2H_2O$ --- 2NaOH + Cl_2 +H

The depleted or return brine is sent back to the brine saturation tank where the concentration is increased by adding NaCl. During Electrolysis some amount of water from brine will be transported to the cathode compartment along with the sodium ions. The water loss from brine is made up by adding DM (Demineralized) water to the depleted brine before it enters the saturator. The temperature inside the electrolyte cell is around 80°C.The NaOH is collected separately in the Catholyte tank. The product is sent to caustic evaporation unit to improve the concentration.This is done by three multi effect evaporator and it takes 2-3 hours.

Hydrogen gas treatment: Wet hydrogen is cooled to remove the water content and get Caustic soda coming from the electrolyzer is cooled in a heat exchanger, a part stream + Demineralized water is recycled back to the electrolysis cell, the other part is sent to storage. Concentration and flaking: Caustic soda can be concentrated up to 48%. The 48% caustic could then be further concentrated and solidified in flakes for commercial purpose

Hydrochloric acid synthesis: Hydrochloric acid is produced from H2 and Cl2 gases, after their cooling and filtration in a hydrochloric acid synthesis unit. The HCl Synthesis reactor includes the burner, the hydrochloric acid absorber and tail scrubber in order to avoid atmospheric air pollution. Reaction is highly exothermic. Sodium hypochlorite is produced by intimate content between NaOH and Chlorine. Reaction takes place under continuous operation in a liquid jet ejector.The chlorine gas can be delivered to reaction section after cooling; a tail tower fed with fresh caustic remove any chlorine trace.

Brine Treatment Brine dechlorination :For effective dechlorination, chlorinated brine of under normal operating conditions is acidified by adding HCl in the line before entering the depleted tank. Most of the free chlorine exceeding the equilibrium solubility under acidic brine conditions escapes to the main chlorine gas header .The brine is then sent to the dechlorination tower. In the dechlorination tower, free chlorine is stripped from the chlorinated brine by lowering the chlorine gas equilibrium partial pressure. At the tower outlet, the active chlorine content in the brine will be as low as 20 ppm. This dechlorinated brine after the tower outlet is called “lean brine”. The dechlorinated brine is collected in a dechlorinated brine tank. The condensate collected from the hydrogen gas cooler is also added in this tank. The lean brine is neutralized with NaOH. The Na2SO3 solution is added to the lean brine to eliminate the active chlorine content completely

The lean brine with no active chlorine is then sent to the saturators for further saturation with the raw salt. A part of the lean brine is purged out to maintain the Chlorate level. The Na2CO3 solution is prepared by dissolving Na2CO3 powder in DM water. The HCl required for acidification of brine is collected in the HCl tank and supplied to various users by HCl feed pump. The free Chlorine removed from the depleted brine at the dechlorination tower is sucked by a vacuum pump through recovered chlorine coolers and then sent at a slightly negative pressure to wet chlorine gas main header for further treatment.

Constraints

Sudden current load change will abruptly affect the bubbling ratio in electrolyte and could cause the overflow stream to sprout or stop. Also membrane vibration due to gas pressure fluctuation and the membrane exposure to pressure zone will shorten the membrane life.Therefore the current load should be increased or decreased only gradually. In either case of increase/decrease in current load, the NaCl strength in depleted brine is analyzed and checked if it is more than 180 gpl in order to prevent membrane damage.The DM water supply rate to the recycled caustic soda will be controlled to maintain the caustic soda strength in the catholytic constant.a)Before increasing the current, the DM water flow rate to the valve corresponding to the projected current load is increased. b)The current load is decreased before decreasing the DM water flow rate corresponding to the projected current load.

CASE STUDY 2

Brief Description of the Process:

The plant has five Paper Machines . It manufactures a diversified product range from 58 GSM to 300 GSM of different grades of paper.

1.Chipper House:It is the starting section of pulp mill. In this section a grape machine is there which grape the bamboos and the hardwood and throw them into the machine after washing them. Washing of bamboos and wood before chipping is done to reduce dust and to increase the life of the knife. Purpose of Chipping is to reduce the logs to wood fragments of a size (25x10x5) which facilitates the penetration of cooking liquor during pulping. Capacity of the Chipper: 190000kg/batch.(1852000 kg/batch is sent from chipper to the screen.

2.Screen: Chip Screen is provided with two section of plates. The first section is provided with 45mm hole plates , that helps in separating the oversized chips. Second section or bottom section with 5 mm holes separating dust from the screen. After Chipping the chips are screened, usually by vibrating or gyrator screens. Screening is necessary to separate oversize chips which would be unsatisfactorily penetrated by cooking liquor and increase rejects and might cause mechanical problem like jamming etc. Similarly an undersized or saw dust fraction is also removed (3% of the wood).The oversized fraction is sent to a Rechipper and screened again.

3. Re Chipper: There are two Drum type Re Chipper. Chips are rechipped that comes from the screen through the conveyer belt and again taken to the Chip Screen . So around 16% of the total chips comes to the Rechipper. A Metal Detector is there to remove the Metal Particles during processing which is situated before and after the chipper. A Screen is used to Separate under and Oversize Chips.Chips are stored in Silos. Chip Silos are large Concrete constructions in which chips are introduced from the top and are

extracted from the bottom by suitable discharge mechanism.(Usually a screw arrangement.).Dust Silo: Generated dust is collected in the Silo and then sent to the Power House as Boiler Fuel.Ground Floor Silo: Used to store accepted chips. 8 Silos are there (5 for wood and 3 for bamboo). On the top of the Silo the conveyor belt is provided with 4 deflectors, which deflects the chips into the respective Silos. There are 3 screw extractors below the Silo, two are in function and one is in standby. After the screw extractors are opened chips fall on the conveyor on below of the Silo where bamboo and wood chips are mixed in certain ratio as per the screw extractor speed. The conveyor conveys the chips to the washing section for removing dust and silica present in the wood. Then the washed chips are sent to the Live bottom Silo. In the Live bottom Silo the exact bamboo and wood ratio is maintained depending on the requirement of the Pulp Mill. The Live bottom Silo is provided with gamma rays detector , which detects the level of chips in the Silo. Capacity of Live bottom Silo is 100 tonnes. From the Live bottom Silo the Chips are sent to the Digester.

4. RDH Digester:Entire cooking operation comprises of 6 steps and around 4 hours. The fiber yield of RDH process is around 40-42%. Digester is always full. The Liquid Wood ratio is 5:1.Chips are cooked in the digester. Chips are conveyed to the digester with a moisture content of around 25%.

5. Fiber Line: It is an advanced technology where the cooked Pulp is subjected to screening , washing and bleaching controlled by distributed control system.(DCS).

6. Disc Knotter: Cooked Pulp from the discharge tank is pumped to the disc Knotter for separation of Knots (uncooked chips)from the Pulp. Number of Knotter: 02 , Rejection is 1%

7. Brown Stock Washing: Brown stock washer is used to wash out the residual liquor from the cooked pulp by means of vacuum filter with closed hood to prevent the pulp contamination during subsequent pulping process. Chemical loss is around 1.6%.

8. Screening: To separate the unwanted , troublesome and oversized materials from the cooked pulp for uniform processing. There are 3 stages of screening with different perforation ,Primary Delta Screen , Secondary Delta Screen , Tertiary Delta Screen.

9. Displacement Press: The pulp is squeezed by passing between the two horizontally placed rolls. Out of two Rolls one roll is rotating and other is stationery. Which results in good water removal and the consistency is increased to 30-35% (outlet consistency) from 3-5% (inlet consistency). There are two Displacement Press DP-I and DP-II. The Pulp is diluted with a part of filtrate from DPII and oxidized white liquor is added to raise the pH required for Oxygen delignification. Soda loss at DP-II is around 2.4% of pulp.

10.Oxygen Delignification: The Oxidized white liquor contains minimum NaOH and Na_2O. The Oxidizing efficiency is more than 85%. Oxygen delignification is carried to control bleaching chemical requirement in bleaching stages and to reduce pollution. Oxygen dozing is given in the T-mixer at 14-18 kg/ton of pulp. The mixed pulp is then subjected to oxygen reactor to carry out delignification. The Oxidized and delignified pulp is pumped to DP-II where hot water is used for washing spray and the pulp is squeezed to increase the consistency to about 30-35%. The Pulp is then taken to DP-II dilution screw where warm water is used for dilution .The medium consistency pulp is pumped to unbleached tower .

11. Post Oxygen Washing: After Oxygen delignification good washing of the pulp is necessary since black liquor solids consume oxygen and may adversely affect the selectivity.

12. Bleaching of Pulp: It is carried out to improve the brightness of the Pulp by using different chemicals.

13.Soda Recovery: The black liquor from digester house is not drained, in order to minimize water pollution .Soda recovery plant not only minimize pollution but also make the paper production economical by recovery and recycling chemicals used for cooking. Heat of black liquor is used for generating steam for use in power generation system. Recovery of chemicals has always been considered as the back bone of pulp and paper industry . It is called Soda Recovery because it receives black liquor from pulp mill (fiber line) and convert it into white liquor. Process Details- It consists of 3 main section: Evaporator Plant ,Recovery Boiler , Causticizing Plant Evaporators: Evaporators are used to remove large amount of water from weak black liquor . It is first step in the process of recovering the chemicals. Recovery Boiler: Dehydrating the black liquor and burning the organic constituent with maximum combustion efficiency, Reducing the portion of the chemicals present as Na_2SO_4 and other sodium sulphur or oxygen compound ,Melting the inorganic chemicals for continuous removal in molten form, Conditioning the products or combustion to reduce the chemical carry over the flue gas temperature.Causticizing Plant :Green Liquor: The liquor that results when the inorganic smelt from the recovery furnace is dissolved in water is called "green" liquor.Causticizing: It is the process in which Green Liquor is converted in to White Liquor. Technically speaking it is the process of converting sodium carbonate in to sodium hydroxide. Causticizing plant convert the green liquor into white liquor .The clarified white liquor. from the Causticizing plant is used in cooking.

14.Stock Preparation: Stock preparation is the next stage of pulping in the paper making process. Paper making fibers which are produced by the pulp mill are not suitable for manufacturing of quality paper. Stock preparation supply prepared stock uninterruptedtedly to machine with maintaining required quality parameters in the stock as well as paper to reduce non-conformity products.In stock preparation various components of furnish are stored in chests, refined and blended together with non fibrous material in relative proportion required by the paper grade.There are two main constituents of papermaking furnish:1.Fibrous raw materials (pulps) 2.Non-fibrous raw materials (additives)Stock preparation is done to :1. Treat and modify each furnish constituent as required.2.Combine all ingredients continuously and uniformly into papermaking stock.3.Uniformity very important for stable paper machine operation and high paper quality.

Refining: Refers to mechanical treatment of pulp in a water suspension to develop the paper making properties like hydration, fibrillation and to cut the fiber to the desired length distribution. Mixing Chest: It is used for proper mixing of pulp with filler, OBA (Optical brightening agent) , dyes and broke which are manually added.OBA – Used to increase the brightness of the paper. Fillers: Finely divided mineral fillers are added to paper making furnish to improve the Optical and physical properties of the sheet. The common paper making fillers are clay , calcium carbonate , talc and Titanium dioxide. Dyes: These are mainly added for two purposes, to produce a definite colored paper , to improve the whiteness of paper. Broke Chest: Used to increase the efficiency of the plant by reutilization of fibers. In Broke Chest , broke comes from 3 different sections 1. Couch Pit 2.P.F Plant 3.Coating Plant Thickener: Used to increase the consistency of the slurry.Machine Chest: Here the Stock ready to get converted into paper is stored.

15.Paper Machine: Fan Pump: It is used to mix the stock with the white water and deliver it to the head box. It s the largest pump in the paper machine system. Flow rate and pressure are kept stable for proper functioning.

16.Centricleaner: Used to remove high specific gravity contaminants like sand and dirt from pulp and paper stock by a combination of centrifugal force and fluid shear. Screening: The Cleaned stock from primary Centricleaner enters the vertical screens for the removal of shives, dirt and other debris remained in the stock. Head Box: The primary function is to provide a volume where excessive turbulences and cross flows created in the distributor are equalized, inequalities in velocity of flow are corrected and the stock is delivered to the slice.

17. Press Part :A press is a pair of squeeze rolls designed to remove water mechanically and smooth and compress the sheet. The moisture in the web at couch is about 78-80%. It is more economical to remove water from the web by mechanical pressing in the press section than the evaporation of water in the dryer section.Dryers: Drying is defined as the removal of moisture or water from the wet web leaving the press, mainly by evaporation through steam heated cylinders.In drying a sheet of paper, two basic physical processes are involved, heat transfer and mass transferSurface Sizing: The paper is coated with size solution for improving surface properties of paper and enhancing the production of paper. All the paper machines have size press. Calendering: The calendering operation includes the passage of paper through one or more nips formed by asset of chilled iron rolls. The main objectives are: To reduce sheet thickness to desired value ,To even out caliper variation ,To impart desirable surface properties, primarily smoothness. Reeling : This is called as pope reel section. After calendering the paper is collected in a convenient form for further processing. For this purpose, the paper machines are equipped with drum reels. Coating :The main reason for applying a coating to paper is to improve printability and appearance. Coating is the treatment or application of pigments polymers, or others materials to one or both surface of paper. The Coating solution consists of following ingredient Pigment , pH controller , Binder , Deformer , Dispersants , Dyes , Lubricant ,OBA ,Preservative uper Calendar : Super calendar is used to impart gloss & smoothness to some grade of papers. Super calendar is a multiroll calendar composed of alternative hard and soft rolls. Finishing House :Finishing is the final operation of the product. It is a process which converts semi completed paper from paper machine room into salable product. Purpose of finishing is to meet the customer demand: Finishing operation consists of Roll Finishing , Sheet Finishing Rewinders (Roll Finishing): Rewinders are used to wind the paper properly Sheet Finishing (Sheet Cutter) :Cutter is a device used to convert the continuous web of paper coming from reel to sheets of specified length and width as specified by customers. Sorting (Removing the defective papers) ,Counting ,Packaging, Wills Cutter .In Wills cutter; JK copier [A4 size] cutting is done & counting & packing is done automatically.