INTELLIGENT SHORT TERM SCHEDULING OF A PRODUCTION CELL WITH PARALLEL FACILITIES

Esko K. Juuso[1], Harinder Singh Jagdev[2]

[1]Control Engineering Laboratory,
Department of Process and Environmental Engineering,
PO Box 4300, FI-90014 University of Oulu, Finland
[2]University of Manchester,
PO Box 88, Manchester M60 1QD, United Kingdom

esko.juuso@oulu.fi(Esko K. Juuso)

Abstract

For production planning and scheduling, optimization is the basis of the decision making: the number of possible alternatives is reduced by comparing alternative fuzzy values of the objective function. For the mid term scheduling, an aggregate optimization problem is handled by an optimization-based inference engine. Decision making in the short term scheduling has usually several feasible alternatives, and therefore, some preference criteria can be used as well. The main idea is to select clusters and items in such a way that the risk of delay in the end of the scheduling period is minimised. The scheduler consists of three phases: (1) allocation, (2) selecting clusters to the active queue and (3) selecting items for processing. Factory topology, resource requirements and product demand may change within the scheduling period, and the scheduler returns to the previous phases if significant changes take place. Allocation is performed for *clusters* in each subset by LPT (longest processing time first) rule. For detailed scheduling, the linguistic equation approach provides a method for a smooth adaptation of scheduling rules to the changing operation conditions and an efficient method in representing the preferences and priorities from process requirements and available resources. The fuzzy scheduler expands the ideas of the knowledge-based scheduler in a flexible way by using fuzzy reasoning in selecting cluster to the active queue and then items for processing. According to test runs with combined fluctuating problems, the intelligent scheduling approach is a robust solution for short term scheduling.

Keywords: scheduling, linguistic equations, fuzzy set systems, manufacturing, discrete event simulation.

Presenting Author's Biography

Esko K. Juuso has M.Sc. (Eng.) in Technical Physics from University of Oulu. He is currently a senior assistant in Control Engineering at University of Oulu, Oulu, Finland. He is active in Finnish Simulation Forum (FinSim), Scandinavian Simulation Society (SIMS) and EUROSIM, currently he is chairman of FinSim. His main research fields are intelligent systems and simulation in industrial applications, including software sensors, control and fault diagnosis. For these applications he has introduced the linguistic equation (LE) methodology.

1 Introduction

For production planning and scheduling, optimization is the basis of the decision making. In *production scheduling*, the coordination of the coupled processes is the main task. The scheduling problem is structured in a two level hierarchy [1]. On the upper level, the aggregate lot-size scheduling model is obtained from detailed scheduling problem by simplification and aggregation of periods, products and resources. The lower level performs detailed scheduling of each short period.

Scheduling of semi-continuous systems in changing operating conditions is a challenging problem. A facility can consist of a single machine or a series of machines acting as a flow line, and it can operate in a continuous, semi-continuous or batch mode. From the scheduling point of view, the operations can be categorised based on the variety of set-ups or change-overs incurred during scheduling.

For the *mid term scheduling*, an aggregate optimization problem is handled by an optimization-based inference engine [1]. Fuzzy logic is useful both in generating the aggregate values of the family parameters and disaggregating the resulting lot sizes into demands for each individual item. In the *short term scheduling*, the solution of the aggregated problem allows the detailed scheduling problem to be decomposed into smaller subproblems. The objective of each subproblem is to schedule the workload for each period in the given time span so that the resources are utilized in the most efficient way and all realistic constraints and conditions are satisfied.

A knowledge-based system presented in [1] is based on filling all realistic constraints and conditions. The detailed schedule is generated in two stages:

- Allocation stage distributes the workload among various resources.
- Scheduling has two stages, i.e. clusters and their items are transferred through an intermediate queue called the *active queue* into the schedule.

As there are several alternative clusters, some preferences and priorities can be used. An inappropriate sequence of rules may drop out all the alternatives. This problem can be alleviated by using fuzzy rules. Concepts of importance and usefulness were introduced for each preferences and priorities in [2]. The resulting fuzzy scheduler expands the ideas of the knowledge-based scheduler in a flexible way [3].

Expert systems, heuristic search, intelligent methodologies and nature inspired systems have been used scheduling problems. Perturbations can be handled by fuzzy controllers, e.g. a neuro-fuzzy method for solving scheduling problems in real time was presented in [4]. Knowledge-based systems and simulation were combined in to assist the production manager in handling production disturbances [5]. Requirements of manpower management were emphasized in [6]. A genetic algorithm was proposed for the multi-level, multi-machine proportional lot sizing and scheduling problem [7]. Evolutionary algorithms and simulated annealing were proposed to search for solutions to machine scheduling problem and optimal design in manufacturing systems [8]. An ant colony optimisation-based system for solving FMS scheduling in a job-shop environment with routing flexibility, sequence-dependent setup and transportation time [9]. Heuristic algorithms based on processing times were introduced in [10, 11]. An immune algorithm was proposed for handling sequence dependent set-up times [12].

Planning systems should help overall manufacturing systems to master huge amount of data [13]. Similar problems can be found in most processing industries, such as chemical, pharmaceutical, food and cosmetics, and various manufacturing industries, such as textile or electronics manufacturing. Quantitative analysis techniques of scheduling can be utilized in managerial decision making [14] and multilevel process control [15].

This paper extends the intelligent scheduler presented in [3] to cases with fluctuations of resource requirements and demand combined with possible changes in factory topology.

2 Manufacturing cell with parallel facilities

The methodology described in this paper pertains to the scheduling of a single stage manufacturing cell consisting of several parallel facilities. A facility, which may operate in a continuous, semi-continuous or batch mode, can consist of a single machine or a series of machines acting as a flow line (e.g. transfer lines) where only semi-active schedules are considered. This cell can be a stand alone type of manufacturing or form a part of a larger manufacturing set-up consisting of a network of cells arranged, in terms of work flow, in series, parallel or a combination of the two.

From the scheduling point of view, such manufacturing operations can be categorised based on the variety of set-ups or change-overs incurred during scheduling. One possible classification based on the set-up times (or costs) is:

1. Set-up times are independent of the sequence in which the items are processed.
2. Set-up times on the facilities are sequence dependent:
   (a) The set of jobs can be divided into families such that set-up times (or costs) within a family of jobs are similar to one another and significantly smaller than from one family to another.
   (b) There are more than two types of set-ups or, a completely general case where the sequence dependence cannot be classified into any order.

Class of problems in category 1 form a sub-set of category $2a$. Any solution generated for $2a$ class of prob-

Tab. 1 List of Items and their relationship with products and sizes [3].

	Size						Dedication Matrix			
Product	1	2	3	4	5	6	1	2	3	4
1	-	-	1	-	2	3	0	0	0	0
2	-	4	5	6	-	7	0	0	0	0
3	-	-	8	-	9	-	0	0	0	0
4	-	-	10	-	11	-	0	0	0	0
5	-	-	12	-	13	-	0	0	0	0
6	-	-	14	-	15	16	0	0	0	0
7	17	-	18	-	-	-	0	0	1	0
Capability Matrix										
1	0	1	1	1	0	0				
2	0	0	0	1	1	1				
3	1	0	1	0	0	0				
4	0	0	0	1	1	1				

lems will also solve category 1 type of problems. Our focus of attention in this paper is on a class of problems falling in category $2a$.

In cases where the cell forms a part of a larger complex, it is assumed that the schedules generated will be acceptable to operations downstream to the cell (such as warehousing) and the facilities upstream to the cell will be able to meet the requirements of the cell schedules. To retain real life perspective, the methodology does consider constraints imposed by basic upstream mechanisms such as the number of storage silos and the number of materials handling equipments available to transfer products from storage system to the processing facilities in the cell.

In such manufacturing environments, normally, the materials going into the cell are already finished products which get processed by the facilities in the cell to produce specific items. Usually, a product can be processed in several ways to produce different items giving rise to two attributes for each item: the *Product attribute* which specifies the product which goes on to make the item and the *Processing attribute* which defines it's processing requirements (e.g. which of the available facilities can perform the required processing and the corresponding times and ancillary requirements). The basis of relationship among various items in a family will be defined either by the processing attribute or the product attribute.

3 Short term scheduling problem

In the Short Term Scheduling, the solution of the aggregated problem allows the detailed scheduling problem to be decomposed into smaller subproblems. The objective of each subproblem is to schedule the workload for each period in the given time span so that the resources are utilized in the most efficient way and all realistic constraints and conditions are satisfied [1]. Processing time and manpower as well as previous subprocesses are taken into account.

The detailed schedule is generated in two stages: *Allocation* and *Scheduling*. Allocation stage distributes the workload among various resources classified on the basis of the *factory topology* into two categories: (1) facilities dedicated to a product, and (2) general purpose facilities. The second stage schedules the workload distributed among the facilities by the allocation stage. The scheduling stage also consists of two stages to take into account sequence-dependent set-up times.

3.1 Factory topology

The cluster formation is defined either by the processing attribute or by the product attribute. All subsets of facilities, i.e. the general purpose facilities and all the dedicated subsets of the facilities have their own clusters.

The *product* and *size* combinations form the *items*, and *facilities* have some restrictions on which products and sizes can be processed. Facilities are either dedicated or general purpose lines. The topology of the factory is defined by three matrices:

- Items definition matrix,
- Dedication specification matrix,
- Facility capability matrix.

Properties defining the items and the capabilities of the facilities depend on applications. For packing lines, classification is based on products and package sizes, e.g. in Tab. 1 the definition matrix defines 6 size clusters. As the product 7 is dedicated to the line 3, items 17 and 18 can be packed only there. Cluster 2 can be packed only on the line 2 but the other clusters have at least 2 alternative lines. [3]

On the Scheduler implemented on Matlab, the topology can changed on any time. Naturally, all the changes require a reallocation of the work load on the basis of the remaining demand updated with new demand.

Tab. 2 Processing rates (numbers of units processed per minute) of items and the corresponding manpower requirements.

	Process Matrix				Processing Rates				Manpower			
	Facility				Facility				Facility			
Item	. 1	2	3	4	1	2	3	4	1	2	3	4
1	1	0	0	0	62	-	-	-	3	-	-	-
2	0	1	0	1	-	83	-	83	-	3	-	3
3	0	1	0	1	-	83	-	83	-	3	-	3
4	1	0	0	0	54	-	-	-	3	-	-	-
5	1	0	0	0	62	-	-	-	3	-	-	-
6	1	1	0	1	73	73	-	73	3	3	-	3
7	0	1	0	1	-	83	-	83	-	3	-	3
8	1	0	0	0	62	-	-	-	3	-	-	-
9	0	1	0	1	-	83	-	83	-	3	-	3
10	1	0	0	0	62	-	-	-	3	-	-	-
11	0	1	0	1	-	83	-	83	-	3	-	3
12	1	0	0	0	62	-	-	-	3	-	-	-
13	0	1	0	1	-	94	-	94	-	3	-	3
14	1	0	0	0	62	-	-	-	3	-	-	-
15	0	1	0	1	-	94	-	94	-	3	-	3
16	0	1	0	1	-	83	-	83	-	3	-	3
17	0	0	1	0	-	-	25	-	-	-	3	-
18	0	0	1	0	-	-	31	-	-	-	3	-

3.2 Resource requirements and demand

Resource requirements are defined by processing rates and manpower requirements. Processing rate and manpower requirements must be given for all the item facility combinations (Tab. 2). The availability of the values is then checked, and the missing values are asked from the user during the allocation phase. [3]

The setting of a facility from one family to another is normally called a *major change-over* and the re-setting within a family is termed as the *minor change-over*. The term change-over need not always imply a physical re-setting of the facility. It is the loss in productive time, accompanied by the consumption of certain resources, when the production is switched from one item to another.

Manpower resources could change in any scheduling point already in the system presented in [3]. In the present system, all resource requirements and manpower availability are defined by probability distributions. The processing time may also be effected if the manpower resources are not filled completely.

Also demand can change also within the short term, and new items or considerable changes in demand of the exiting items will require reallocation.

3.3 Allocation

Allocation stage distributes the workload among various resources classified into two categories: (1) facilities dedicated to a product, and (2) general purpose facilities. As described above, the first category can be divided into several subsets. Since the subsets do not overlap, these subproblems can be solved separately. For each subproblem, a process matrix is obtained by the items definition matrix and the capability matrix developed for the subset of facilities. The processing time is calculated for each alternative from the demand and the processing rate matrix. Load smoothing is included if necessary and possible.

Allocation is performed for *clusters* in each subset by *LPT (longest processing time first)* rule in the following steps of facilities:

1. allocate clusters which are accepted by only one facility - there is no choice in allocation,
2. allocate other clusters on the subset by LPT rule,
3. smooth the allocated load, if necessary.

While performing the allocation by the *LPT (longest processing time first)* rule, variations in the processing rates of facilities is taken into account. At this stage, the facilities are decoupled from one another, and the constraints coupling them together, such as the total manpower available, are ignored.

It should be noted that the above rule does not guarantee the optimal distribution of the workload. Since the solutions merely act as seeds to detailed scheduling, it is not necessary to generate optimal workload distribution at this stage. In fact, it has been noticed that optimal workload distributions, e.g. obtained through *LP* or *MILP*, at this stage do not guarantee much better solutions than those obtained from simple *LPT* rules. This is understandable if we note that the facilities are not identical, various items can have varying manpower requirements, there is limit on total manpower available, and there are constraints on number of products that can be simultaneously processed.

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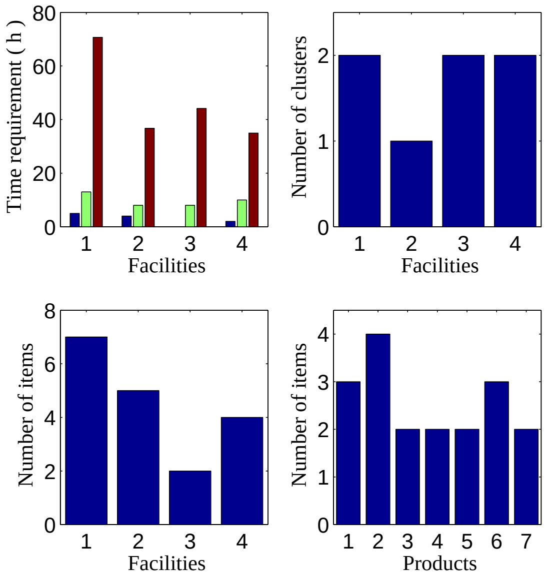

Fig. 1 Allocation results.

The problem tackled in this paper is so complex that comparison between the makespan obtained by LPT rule and the optimal makespan is not possible, especially when uncertainty is taken into account.

The allocation result provides information on importance of different features. Short term scheduling case of packing lines defined by Tables 1 and 2 has been used as an example [3]. Clearly, the work load cannot be evenly distributed since some size clusters can packed only on a single packing line (Fig. 1). The allocated clusters and items, the corresponding processing times, the cumulated change-over times define the minimum possible makespan times for each facility. Number of clusters does not have big difference between the lines. Number of items has more differences between lines and products as well. The number of items on a product is used as a priority of that product in the scheduling.

Allocation and also reallocation is done for the remaining workload which means that any changes in factory topology, resource requirements or demand can be taken into account. Uncertainties are handled with probabilistic distributions.

3.4 Scheduling

The original scheduling algorithm is a recursive, single-pass algorithm which analyses the current state of schedules, the facilities and the unscheduled workload [1]. The decision can be the introduction of idle time, setting or the starting of processing of an item on a facility at any given time. Special rules have been developed for avoiding deadlock situations.

Actually, there are two stages: the clusters are transferred through an intermediate queue called the *active queue* into the schedule. An item for processing is selected from the active queues. The selection of a cluster to the Active Queue is based on the algorithm taking into account several criteria. Usually, there are several alternative clusters, and some preference criteria can be used as well. Difficulties in sequencing these criteria can be removed by fuzzy logic approach.

The selection of a cluster to the active queue is based on the algorithm taking into account several criteria:

- available manpower (operators and setters),
- maximum allowed number of products,
- connections to other parts of the production system.

In the present system, considerable changes in resources availability and demand, as well as interactions between processing or change-over times can be handled with the scheduling algorithm. Reallocation is done only if the workloads of facilities become highly unbalanced.

Usually, several alternative clusters could be selected, and therefore some preference criteria, e.g.

- maximum processing time requirement,
- maximum number of clusters,
- maximum number of items,
- priority of the products, and
- product just finished,

can be used as well. These are used in the selection of facility. After selecting the facility, cluster is chosen, usually on the basis of the product priorities. In the deterministic procedure, an inappropriate sequence of these criteria may drop out all the alternatives. This difficulty can be removed by fuzzy logic approach [3].

4 Intelligent scheduling

Fuzzy preferences and priorities improve performance of the knowledge-based scheduler [3]. Large fuzzy set systems can be represented in a compact form with linguistic equations [16, 17].

4.1 Importance of scheduling filters.

For short term scheduling, the preferences related to some filters of the recursive fuzzy algorithm can be quantified by using importance variables for variables:

- remaining processing time requirement,
- number of clusters, and
- number of items.

On the other hand, the usefulness of each fuzzy filter depends on the value range of the corresponding variables in the set of alternative clusters (or items). Since

Tab. 3 Fuzzy decision making on the basis of preferences.

Properties		Degree of Membership				
Name	Value range	Facilities				Minimum
	min ... max	1	2	3	4	value
Processing time	1736 ... 3990	1.0000	0.0567	0.5412	0.0000	0.00
Number of items	2 ... 7	1.0000	0.8240	0.5000	0.6760	0.50
Product priorities	4 ... 20	1.0000	0.6250	0.2500	0.7627	0.25
Overall preferences						
- Maximum		1.0000	0.8240	0.5412	0.7627	
- Minimum		1.0000	0.0567	0.2500	0.0000	
- Algebraic product		1.0000	0.0292	0.0677	0.0000	
- Bounded product		1.0000	0.0000	0.0000	0.0000	

Tab. 4 Fuzzy decision making on the basis of preferences.

Properties		Degree of Membership			
Name	Value range	Facilities			Minimum
	min ... max	2	3	4	value
Processing time	1736 ... 2925	0.5697	1.0000	0.4725	0.4725
Number of items	2 ... 5	1.0000	0.9000	0.9741	0.9000
Priorities	4 ... 14	0.9610	0.6250	1.0000	0.6250
Overall preferences					
- Maximum		1.0000	1.0000	1.0000	
- Minimum		0.5697	0.6250	0.4725	
- Algebraic product		0.5475	0.5625	0.4603	
- Bounded product		0.5307	0.5250	0.4466	

both the importance and the usefulness can be represented by linguistic variables, the overall importance of each fuzzy filter can be solved by linguistic relations. [2]

The overall importance increases with increasing importance of the variable, and increasing value range of the variable. This can be represented by relations $importance(x, y, z)$ where x, y and z are the linguistic values for the overall importance, the importance of the variable, and the value range (or the usefulness of the criterion), respectively. Each relation describes which linguistic values belong together, e.g.

$$importance(normal, normal, normal)$$
$$importance(low, high, normal)$$

This model consists of 25 linguistic relations if each variable has five linguistic labels: $very\_low$, low, $normal$, $high$, and $very\_high$. [2]

With linguistic equations this set of rules can be represented by a single equation: the overall importance = importance of the variable + usefulness of the filter, where the original linguistic labels correspond to the real values -2, -1, 0, 1 and 2.

The importance of each variable can be given as an input for each scheduling period. However, it is also possible to estimate them by additional linguistic models which take into account the relative lengths of the processing time and different change-over times. This estimation is performed only in the beginning of each scheduling period, and the purpose of the usefulness variable is to adapt the preferences into changing operating conditions. Reallocation also starts re-estimation of the importance of the filters.

All these relations are changed into the equation form, and only the resulting aggregated relation set is consulted on the linguistic relation level. Monotonous scaling functions presented in [17] provide a nonlinear interface for handling the properties.

The degrees of membership are chosen to be one for alternatives which come up to the requirements. For a very important filter, the degree of membership should be close to zero for other alternatives, i.e. the filter is almost crisp. For an unused filter, the degrees of membership are one. Therefore, all the gradual importances can be taken into account and even the passing subset of alternatives can chosen by these preference variables. Processing time provides a strong filter in the decision situations shown in Tabs. 3 and 4.

The degrees of membership are combined with fuzzy reasoning, examples shown in Tabs. 3 and 4. The minimum method, which weights the overlap as much as possible [18], suits well to applications where smoothly changing results are preferred. Various families of T-norms [19] are not useful in this application since they all produce smaller grades of membership than the *min* operator which is the upper bound of T-norms. The maximum method discounts the overlap between

Tab. 5 Selecting items for processing.

	Facilities		Most Important	Cluster	Items		Product
	Selected	Competitors	Filter		Selected	Competitors	
1	1	-	-	3	5	1,8,10,12,14	2
2	3	-	-	1	17	-	7
3	2	-	-	5	15	2,9,11,13	6
4	1	-	-	3	1	8,10,12,14	1
5	4	2	product finished	6	7	3,16	2
6	1	2	processing time	3	14	8,10,12	6
7	2	4	product finished	5	2	9,11,13	1
8	4	2	product finished	6	3	16	1
9	1	2	processing time	3	12	8,10	5
10	2	-	-	5	11	9,13	4
11	4	3	product finished	6	16	-	6
12	2	3	processing time	5	9	13	3
13	1	3	processing time	3	10	8	4
14	3	-	-	3d	18	-	7
15	2	-	-	5	13	-	5
16	1	4	processing time	3	8	-	3
17	4	-	-	4	6	-	2
18	1	-	-	2	4	-	2

the known variables [18]. The bounded sum [18, 20] weights the overlap as much as possible.

Different set of parameters can be used in scheduling clusters and in selecting items for processing. The actual values of preference variables depend on the set of alternatives under consideration, and the active set changes also during the scheduling period.

4.2 Selecting clusters to the active queue

The allocated workload is scheduled by taking into account resource requirements. In the methodology tests, the constraints were not very hard since following resources are available for the whole period: 10 operators, 4 setters, and 7 products can be packed at the same time. This means that only one packing line can have a major change-over at a time, but three lines can be running simultaneously.

In the beginning, all the facilities have clusters available, operators are available, and new products could be allowed. However, all the facilities would need a major change-over, and therefore, a time step equal to that is taken before continuing the scheduling. Then the major change-over could be incorporated on any facility, and the setters can be found as well.

After these strong requirements, there are 7 cluster alternatives meaning that the selection can be based on preferences and priorities. In this case, important preferences are shown in Tab. 3. All these preferences support strongly facility 1 which is selected. From cluster alternatives, cluster 3 is selected on the basis of the product priority index. The selection sequence of facilities and clusters is presented in Tab. 5.

Other clusters cannot be selected since there are no setters available. A new cluster can be allocated after a time step equal to the major change-over, and the selection on the basis of the preferences (Tab. 4) is not so clear in this case since different preferences support different facilities: maximum method gives membership value one for every facility. However, the importance of the different filters is not equal, and therefore, all the T-norms can find a difference. The minimum method and the algebraic product have same result, facility 3, but the bounded product selects facility 2. When using the drastic product no difference can be found since the degree of membership becomes zero for all the facilities. The minimum method is used as a default in the scheduler. Selecting the cluster for facility 3 is much easier: cluster 1 has the highest priority index (Tab. 5).

The scheduler has also another procedure if this had not produced a solution: all the cluster alternatives could have been compared by combining the cumulated priority index with different priorities. This would have not changed the result in this case.

Again a time step equivalent to the major change-over must be taken before a new cluster can be selected. A slight difference in the processing time gives preference to facility 2 which has only one cluster. Facility 4 has to wait until operators and setters are available. From its two clusters, cluster 6 is chosen on the basis of the cumulated priority index.

After these cluster selections, all the facilities with remaining work load are active, and the remaining clusters 2, 3 and 4 must be waiting until the active queues of the corresponding facilities 1, 3 and 4 will be empty. Facility 3 is the first one to take a new cluster, then facility 4, and finally facility 1. All these cases have only one cluster alternative.

In the present scheduler, the parameters may also change at any decision point as the workload may change.

4.3 Selecting items for processing

In the example described here, the selection of items does not have as many alternatives as in selecting clusters to the active queue. Actually, in many cases only one facility at a time is able to take a new item for processing, and if that facility has only one item in the active queue there are not many alternatives. The number of facilities waiting for an item depends on the resource restrictions.

The filter based on the remaining processing time requirements is the most important method of selection here as well. In some cases, usually when facility one is not involved, the filter based on the product just finished becomes important (Tab. 5). Changes of processing times in the facilities have a direct effect on the item selection.

The filter based on the importance of the products has the main effect in selecting an item from the active queue of the chosen facility. The final starting time of the packing may change considerably if there are fluctuations in manpower. Drastic changes may also require changes to the active queue (Section 4.2) or even reallocation (Section 3.3).

5 Scheduling results

Several cases have been tested with discrete event simulation. Fluctuations of demand and processing times were taken into account by probabilistic distributions.

Case 1: Non-uniform workload.

The facility 1 was kept all the time running by utilizing the flexibility and idle time in other lines. The filter based on the remaining processing time was the decisive one in all the cases where the facility 1 was involved. The minimum makespan was kept, and Operators had a smooth workload all the time after the change-overs were performed. In some cases, processing could be continued by using a product which just had been finished on another facility.

Case 2: Non-uniform workload with restrictions in product availability.

Some additional tests were performed for the scheduler, and the second one described here is a case where the availability of the most important product was restricted. According to the original schedule, the product 2 is processed in the two items which were scheduled last. Although, difficulties could have be expected the facility 1 was kept all the time running, again by utilizing the flexibility and idle time in other lines. The filter based on the remaining processing time was the decisive one in all the cases where the facility 1 was involved. The minimum makespan was kept, and operators had a smooth workload all the time after the change-overs were performed. Even with these restrictions, processing could be continued in many cases by using a product which just had been finished on another facility.

Changes are mainly seen on the selection of items since the selection of cluster does not have many alternatives in this simple example.

Case 3: Non-uniform workload with restrictions in manpower resources.

The third test described here is a case where the availability of the manpower was restricted for a short time during the scheduling period. The facility 1 was kept all the time running, again by utilizing the flexibility and idle time in other lines. The filter based on the remaining processing time was the decisive one in all the cases where the facility 1 was involved. The minimum makespan was kept, and operators which were available had a smooth workload all the time after the change-overs were performed. The workload remains high till the end of the scheduling period. Even with these restrictions, processing could be continued in many cases by using a product which just had been finished on another facility.

Again changes are mainly seen on the selection of items since the selection of cluster does not have many alternatives in this simple example.

Case 4: Non-uniform workload with late restrictions in manpower resources.

The fourth test described here is a case where the availability of the manpower was restricted in the end of the scheduling period. The facility 1 was kept all the time running, again by utilizing the flexibility and idle time in other lines. The filter based on the remaining processing time was the decisive one in all the cases where the facility 1 was involved. The minimum makespan is kept. However, this was done by increasing the number of setters in the beginning of the period. Operators had a smooth workload all the time after the change-overs were performed. Even with these restrictions, processing could be continued in many cases by using a product which just had been finished on another facility.

Case 5: Combined disturbances.

In the cases presented above, changes are mainly seen on the selection of items since the selection of cluster does not have many alternatives in this simple example. Further improvement of the schedule could be possible since there are two situations where operators are waiting for the end of major change-over. However, the idle time will disappear if only 4 setters were available.

According to long test runs with combined fluctuating problems, the intelligent scheduling approach is a robust solution for short term scheduling problems. The required makespan was not exceeded in these tests since this factory has a lot of flexibility in most of the facilities. The scheduler keeps continuously active the facility 1 where a delay risk is introduced by the biggest cluster (cluster 3). Cluster 4 is packed in the facility 4 to reduce the workload of the facility 1.

Research is continuing with simulation-based tuning of the parameters and definitions of the Fuzzy Scheduler. Also other factories with more demanding topologies are used in these studies.

6 Conclusions

Decision making in the short term scheduling has usually several feasible alternatives, and therefore, some preference criteria can be used as well. The main idea is to select clusters and items in such a way that the risk of delay in the end of the scheduling period is minimised. For detailed scheduling, the linguistic equation approach provides a method for a smooth adaptation of scheduling rules to the changing operation conditions and an efficient method in representing the preferences and priorities from process requirements and available resources. The fuzzy scheduler expands the ideas of the knowledge-based scheduler in a flexible way by using fuzzy reasoning in selecting cluster to the active queue and then items for processing. According to test runs with combined fluctuating problems, the intelligent scheduling approach is a robust solution for short term scheduling.

7 References

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