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Rescheduling: External Environment-related Real-time Events ⋆

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Abstract: When unexpected real-time events occur which cause performance deviations, rescheduling is necessary to update a production schedule if needed. The rescheduling problem concerning external environment-related real-time events is investigated in this paper. First of all, various real-time events are sorted into three categories: productive process-related, production management-related and external environment-related. Then, a new rescheduling framework is proposed to deal with external environment-related real-time events and the framework is detailedly explained with a practical example. We establish knowledge-based analyses to provide scheduling with commands and information by considering external environment-related factors. Finally, a conclusion is given and future work is also mentioned.

Keywords: External environment; real-time events; rescheduling; production management; fuzzy reasoning.

1. INTRODUCTION

As Vollmann et al. (1992) put it, scheduling is "a plan with reference to the sequence of and time allocated for each item or operation necessary to complete the item". In practice, most systems operate in dynamic environments where unexpected real-time events could change the system status, affect performance, and possibly make the existing schedule infeasible. The problem of scheduling in the presence of real-time events, termed dynamic scheduling (Ouelhadj and Petrovic (2009)), is of great significance for the successful implementation of practical scheduling systems. Literature on dynamic scheduling has considered a mass of real-time events, which could be classified into two categories (see Suresh and Chaudhuri (1993); Stoop and Weirs (1996); Cowling and Johansson (2002); Vieira et al. (2003)) in general:

1) Resource-related: machine breakdown, operator illness, tool unavailability or failures, loading limits, delay in the arrival or shortage of materials, defective material (material with wrong specification), etc.
2) Job-related: rush jobs, job cancellation, due date changes, early or late arrival of jobs, change in job priority, changes in job processing time, etc.

Rescheduling in the presence of real-time events is responsible for schedule repairs or generating a new schedule. Regarding the issue of when to reschedule, three policies have been developed in the literature: periodic, event-driven, and hybrid (see Vieira et al. (2003); Ouelhadj and Petrovic (2009)). The event-driven policy denotes that rescheduling is triggered in response to an real-time event that changes the current system state. The majority of approaches to rescheduling are designed by using the policy (see, e.g. Yamamoto and Nof (1985); Vieira et al. (2000a,b)).

In the real world, external environment changes can not only seriously affect the programming of production activities but also destroy production at times. For example, in China, November 11 is the online shopping day for young people. More than 100 million packages need to be quickly and promptly delivered to buyers. Because snow and rains hit some regions in China within a few days of that day in 2012, the express delivery was seriously influenced. It should be also noted that the performance deterioration caused by external environment-related disturbances, such as high temperature and peak seasons of power, is difficult to notice and measure for most of the time. The performance deterioration can be only found by relative quality measures or noting the phenomena that other actions or disruptions have been induced and intensified like rework, quality problems, machine failure, etc. Therefore, in order to increase productivity and reduce operating costs, it is of interest to design a new rescheduling framework to investigate scheduling in presence of external environment changes.

The remainder of the paper is organized as follows. In Section 2, we summarize real-time events into three categories. In Section 3, a practical example–machine shop of a wood furniture factory is introduced. Section 4 is devoted to the main results of the paper. A new rescheduling framework is proposed, and elaborated with the practical example. In the end, the paper is concluded in Section 5.

2. REAL-TIME EVENTS

Because practical systems are confronted with unexpected real-time events in dynamic environments, rescheduling

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is highly needed to update a production schedule when the initially feasible schedule becomes poor and sometimes infeasible. As previously mentioned, such real-time events could be classified into two categories: resource-related and job-related in general. Most literature on scheduling has focused on the two classes of real-time events. Few research publications have been devoted to external environment-related real-time events up to now. On the other hand, we have noticed that external environment disturbances influence scheduling performance, reduce productivity, and incur rework and unnecessary costs frequently; many times, it is only when sufficient time has passed or comparisons are made that these can be found.

As shown in Table 1, we sort real-time events into three categories: productive process-related, production management-related and external environment-related real-time events in order to construct our rescheduling framework in this paper. The overview of real-time events is by no means exhaustive below, and one kind of real-time events can be sorted into different categories in different scheduling problems.

Table 1. Real-time Events

Productive process	machine breakdown, loading limits, delay in the arrival of materials, tool unavailability or failures, operator illness, etc.
Production management	rush jobs, new jobs, job cancellation, change in the priority, etc;
	change in raw material sources, shortage of raw materials, increase or fall in raw material prices, etc;
External environment	power failure, power shortage, power peak season, etc.
	rain and snow weather, strong wind, high or low temperature, high humidity, dry weather, etc.

Based on the classification of real-time events, we will propose a new rescheduling framework so as to deal with external environment-related real-time events.

3. AN EXAMPLE: MACHINE SHOP OF A WOOD FURNITURE FACTORY

The machine shop of a wood furniture factory is introduced as an example to elaborate the rescheduling framework to be constructed. When lumber is placed in certain environment, its moisture content (MC) will tend to an equilibrium value over enough time, which is called as the environment's equilibrium moisture content (EMC). If the lumber MC is higher than the environment's EMC, the lumber will lose moisture and contract; otherwise, absorb moisture and expand. For example, the dried lumber with MC 11% is used to produce wooden products in Guangzhou, which will be sold to Beijing. The annual mean EMC in Guangzhou is 15.1%; however, 11.4% in Beijing. The dried lumber very easily absorbs moisture in the production process, which may cause product quality problems afterwards. Therefore, in order to prevent the lumber MC from being changed largely, it is very important to take technical measures to establish environment of

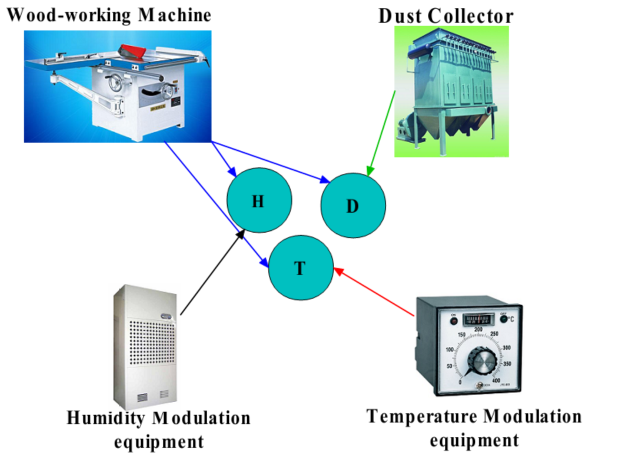

Fig. 1. Devices and requirements of indoor air conditions

low MC. As shown in Fig. 1, humidity modulation equipment is installed to regulate the humidity of the machine shop. In consideration of workers' efficiency and the fact that temperature has some impact on EMC, temperature modulation equipment is also set up to prevent the indoor temperature from being too high or too low in different seasons. In the wood processing shop, wood dust is another issue which cannot be ignored. If the concentration of wood dust exceeds specified limits, it not only endangers workers' health but also probably brings about safety accidents. Hence, dedusting equipment is also indispensable in the machine shop.

Rescheduling in the machine shop addresses what job to start when real-time events happen. From rich human production experience, we can know external environment has important effects on scheduling. For example, it can be seen in the real world that furniture plants in the south generally don't produce the furniture in the rainy season which will be sold to Beijing, unless they have to because of some unavoidable practical reasons, such as rush jobs. No matter what, they always make efforts to avoid similar cases from happening. Otherwise, more electricity will be consumed to dehumidify. It is more difficult in rainy days than in sunny days for the temperature and humidity modulation equipment to keep the indoor environment with low humidity. In the meanwhile, it's evident that a scheduling decision for the machine shop could affect dominantly how to regulate its humidity, temperature and concentration of wood dust by controlling corresponding devices from the introduction to the machine shop. Therefore, by considering the air and machines in the machine shop as a whole, we focus on the way how scheduling adapts to changes of external environment in this paper: When external environment changes, determine what job is suitably started, and, correspondingly, figure out how the air state can be regulated, so that the production cost can be reduced as much as possible with ensuring quality.

4. RESCHEDULING FRAMEWORK

The proposed rescheduling framework is shown in Fig. 2, which will be explained in detail by using the above-mentioned practical example. Firstly, the assumptions are given about the machine shop:

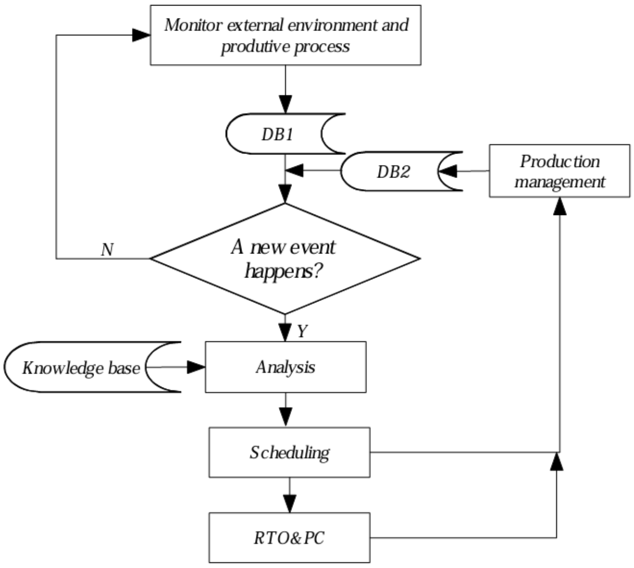

Fig. 2. The proposed rescheduling framework

1. There is a in-process warehouse to store, if needed, unaccomplished lumber;
2. A large order may be split into smaller orders, if allowed, so that one can better arrange the production according to external environment changes.

4.1 A New Event Happens?

The module "A new event happens?" is responsible to judge whether a new real-time event happened according to the data, real-time or non-real-time, collected by modules Monitor external environment and productive process and Production management. In the practical example, we mainly consider two classes of external environment-related real-time events. The first class is about the supply state of power during some time to come. The second is severe weather events. The severe weather may mean rains, snow, or the things that the daily average relative humidity or the average relative humidity for some time to come exceed some preset values, which are determined by experts and different for different dried lumber and orders. When such real-time events happen, the analysis and rescheduling are started.

4.2 Monitor External Environment and Productive Process

The external environment and productive process data are gathered through devices such as sensors or monitors and transmitted to programmable logic controllers (PLC) in analog or digital formats. And then the PLC is used to deal with real-time data and forecasts, and convert them into proper formats. In the end, they are saved in the DB1 database. DB1 consists of three sheets: Productive process real-time data sheet (PPRDS), Power sheet (PS) and Weather sheet (WS). Naturally, productive process-related real-time events in Table 1 would be recorded in PPRDS, and external environment-related real-time events in PS and WS. Some attributes of PPRDS, PS and WS, which may be used in practice, are listed in Tables 2, 3 and 4, respectively.

Table 2. Attributes in PPRDS

FieldName	Remark
MachineID	ID of the machine
MachineState	Operational state of the machine
MaterialDelay	Delay time in the material arrival
ToolID	ID of the tool
ToolState	Service condition of the tool
OperatorID	ID of the operator
OperatorState	State of the operator, such as whether or not the operator is ill

Table 3. Attributes in PS

FieldName	Remark
PeakSeason	Peak consumption season of power
RushHours	Daily peak consumption hours of power
ElectricityPrice	Price for electricty

Table 4. Attributes in WS

FieldName	Remark
Date	Date
AverageRainfall	Daily average rainfall amount
AverageSnowfall	Daily average snowfall amount
MaximumWind	Maximum wind speed
AverageTemperature	Daily average temperature
MaxTemperature	Daily maximum temperatture
MinTemperature	Daily minimum temperature
AverageHumidity	Daily average relative humidity
MaxHumidity	Daily maximum humidity
Minhumidity	Daily minimum humidity

4.3 Production Management

Production management is mainly in charge of job management and resource management, and the latter includes raw materials, machines, etc. Relevant managers establish reliable production tasks, such as orders, according to the requests of customers and the product characteristics, which contain important information about the deadline for delivering goods. Resource management is designed to collect available information with respect to the supply state of raw materials and related knowledge of machines. All the information from Production management is stored in DB2, which is composed of Job sheet (JS), Raw material sheet (RMS) and Machine sheet (MS). Tables 5, 6 and 7 show some potential attributes of JS, RMS and MS, respectively. Besides, as illustrated in Fig. 2, the other task of Production management is to implement the strategies, which have been generated by Scheduling and RTO & PC.

Table 5. Attributes in JS

FieldName	Remark
OrderID	ID of the order
ProductID	ID of products constituting the order
MaterialID	ID of needed raw material
MaterialQuantity	Quantity of needed raw material
NormalTime	Normal production time of the order
EarliestDate	Earliest delivery date of the order
DueDate	Deadline for delivery of the order

4.4 Knowledge-based Analysis

The function of Knowledge-based analysis lies in that when real-time events happen, the analysis gives a com-

Table 6. Attributes in RMS

FieldName	Remark
MaterialID	ID of the raw material
SupplyState	Supply state of the raw maretial
Price	Price of the raw material
Source	Source place of the raw material
TotalQuantity	Total quantity of available raw material

Table 7. Attributes in MS

FieldName	Remark
MachineID	ID of the machine
MachineLoad	Load of the machine, used to judge whether the load is beyond limits
MachinePower	Power of the machine

mand list and a parameter list for Scheduling and RTO & PC based on Knowledge base and DB1, DB2. All the knowledge is stored in Knowledge base, which can be with respect to fuzzy logic, probability distribution, etc. Such related knowledge is applied to obtain the command list and parameter list by reasoning and algorithms.

In the concept of fuzzy logic (Zadeh (1965)), imprecise knowledge can be described by defining membership functions of imprecise values to certain numeric intervals. Fuzzy numbers with membership functions could be obtained by incorporating historical data, prediction knowledge, and experience of the experts. Then, based on DB1 and DB2, we can give the membership function values of the fuzzy numbers for the current external environment. Eventually, the suitability value of every task can be determined through fuzzy reasoning and defuzzification (Leekwijck and Kerre (1999)).

Because some data about real-time events are variable, and sometimes cannot be determined definitely, especially for external environment-related real-time events, it is inevitable that the analysis involves indefinite values. The possible approach for the representation of indefinite numbers is probability distribution. Probability distribution can be adopted to describe qualitative rating values of tasks. For example, Normal or Beta distributions can be used to specify an indefinite duration of tasks. Lognormal or Exponential distributions can be applied to model values of risk assessments.

In the example of the machine shop, we will use fuzzy subsets to describe external environment. Five factors with fuzzy values are represented by linguistic descriptions for ratings such as great, moderate, or low, which are aggregated to decide the suitability of every order. The factors are given: the humidity, temperature, and power supply state during the estimated production time (EPT) of the considered order, the order priority, and the current concentration of wood dust indoor. The humidity and temperature states for some time to come could be obtained from historical data and weather forecasts. The general power supply state during some time to come can be available by referring to the past supply state, such as last year. The numerical evaluations of the three factors when needed are provided by relevant specialists. The order priority can be calculated by the equation

$$OrderPri = \frac{NormalProductionTime}{UsableTimebeforeEarliestDeliveryDate}.$$

The current concentration of wood dust indoor is available from PPRDS in DB1 conveniently.

According to the expert experience, the linguistic values for the forementioned linguistic variables and the order suitability are given in Table 8, and some fuzzy rules for different orders are presented in Table 9 as well. The final exact value of the order suitability can be calculated via defuzzification. And then all the orders are ranked by suitability, and sorted into *SchedulableSet* and *UnschedulableSet* on the basis of the criterion whether the order suitability exceeds a certain constant determined by experts.

For the practical example, the command list is composed of two parts: *SchedulableSet* and Instructions for RTO & PC, where the latter will be supplemented after the scheduling is finished. The parameter list is in charge of providing the optimization models below with related data.

Table 8. Linguistic Values

Humidity (EPT)	Low, Medium, High, VeryHigh
Temperature (EPT)	Low, Medium, High
Power supply state (EPT)	Bad, General, Good
Order priority	Low, Medium, High, VeryHigh
Current concentration of wood dust indoor	Low, Medium, High, Alarm
Order Suitability	VeryUnsuitable, Unsuitable, General, Suitable, VerySuitable

Table 9. Fuzzy Rules for Order 1 and 2

	Order 1:wooden chairs to be sold in Beijing
1	$(High, High, Bad, VeryHigh, High) \rightarrow Suitable$
2	$(Low, Medium, General, High, Medium) \rightarrow Suitable$
3	$(High, High, General, High, Low) \rightarrow General$
4	$\cdots$
	Order 2: wooden beds to be sold in Guangzhou
1	$(High, High, Bad, VeryHigh, High) \rightarrow VerySuitable$
2	$(Low, Medium, General, High, Medium) \rightarrow Suitable$
3	$(High, High, General, High, Low) \rightarrow Suitable$
4	$\cdots$

4.5 Scheduling

In the module, an optimization problem with a cost function is constructed based on the command list and parameter list generated by Knowledge-based analysis. Scheduling decisions can be obtained by solving the optimization problem. In order to give the optimization model of the practical example, the following parameters and variables are introduced:

Now, the optimization model can be formulated:

$$\min \sum_{i=1}^{n} \{T_i \times TC_i + E_i \times EC_i + (CS - CT) \times UC\}$$

subject to:

$$CT < S_1 < F_1 < S_2 < F_2 < \cdots < S_n < F_n,$$
$$F_i - S_i \geq ST_i, \forall i,$$

Parameters

n	number of orders to be produced
ID_j	ID of order
DD^j	due date of order ID_j
ED^j	earliest delivery date of order ID_j
TC^j	cost per day of order ID_j if tardy
EC^j	cost per day of order ID_j if early
ST^j	shortest production time of order ID_j
CT	current time
CID	ID of currently unaccomplished order
UC	warehousing cost per day of unaccomplished lumber for current order

Variables

O_i	ID of order produced during i-th production time interval
S_i	i-th production start time
F_i	i-th production finish time
DD_i	due date of order O_i
ED_i	earliest delivery date of order O_i
TC_i	cost per day of order O_i if tardy
EC_i	cost per day of order O_i if early
ST_i	shortest production time of order O_i
T_i	number of tardy days for order O_i
E_i	number of early days for order O_i
CS	production start time of currently unaccomplished order

$$
\begin{gathered}
ED_i \leq E_i + F_i, \forall i, \\
DD_i \geq F_i - T_i, \forall i, \\
DD_i - S_i > 0, \forall i, \\
O_1 \in SchedulableSet, \\
O_i \neq Q_j, \forall i \neq j, \\
DD_i = DD^j, ED_i = ED^j, TC_i = TC^j, \\
EC_i = EC^j, ST_i = ST^j, if\ O_i = ID_j, \quad \forall i, j \\
CS = S_i, if\ O_i = CID, \forall i \\
O_i \in \{ID_1, ID_2, \cdots, ID_n\}, \forall i \\
E_i, T_i, F_i, S_i \geq 0, \ \forall i.
\end{gathered}
$$

The command list can be updated after the optimization problem is solved. *SchedulableSet* can be replaced with order O_1. Since the first order to be produced has been decided, Instructions for RTO & PC can be given in accordance with product characteristics of order O_1, such as indoor humidity, temperature and wood-dust concentration ranges.

4.6 RTO & PC

RTO & PC is concerned with implementing production scheduling decisions in real time based on the command list and parameter list. For the machine shop, the indoor environment corresponding to order O_1 should be established based on Instructions for RTO & PC. There have been many articles (see Xu et al. (2009); Soyguder and Alli (2009b,a); Sun et al. (2013)) which involve the regulation of indoor air state.

5. CONCLUSION

In this paper, we propose the rescheduling framework to handle external environment-related real-time events. External environment factors, integrated with other factors, have been considered in Knowledge-based analysis to seek the command list for scheduling. However, it's really just the beginning and there is still a lot of work to be done in the future. The subsequent work is to solve the issues: how to generate and update schedules, and test the framework so as to show its feasibility and effectiveness.

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