Scheduling with Fuzzy Methods

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Abstract. Nowadays, manufacturing industries – driven by fierce competition and rising customer requirements – are forced to produce a broader range of individual products of rising quality at the same (or preferably lower) cost. Meeting these demands implies an even more complex production process and thus also an appropriately increasing request to its scheduling. Aggravatingly, vagueness of scheduling parameters – such as times and conditions – are often inherent in the production process. In addition, the search for an optimal schedule normally leads to very difficult problems (NP-hard problems in the complexity theoretical sense), which cannot be solved efficiently.

With the intent to minimize these problems, the introduced heuristic method combines standard scheduling methods with fuzzy methods to get a nearly optimal schedule within an appropriate time considering vagueness adequately.

1 Introduction

Scheduling is a fundamental part of production planning and control. The task of scheduling is the allocation of activities over time to limited resources, where a number of conditions must be preserved. Resources represent objects, which can be allocated by activities. Using ordered sequences of activities, basic production flows can be specified. These sequences, which are mainly predetermined by technical or organizational requirements, are specified by jobs. Jobs can also specify supplementary conditions, as for example deadlines. In manufacturing, a job usually models an order.

2 Basic Approaches

Before the method presented in this paper is sketched, the fundamental basic approaches are considered which led to its development.

At first, reasons for conceptualizing the method as heuristic are given (Section 2.1). After showing that the consideration and processing of vague data, conditions and objectives are necessary (Section 2.2), it is shown how the integration of such information can be achieved in a common way (Section 2.3). Using this potential, it is also possible to integrate varying, partly vague conditions into the scheduling process (Section 2.4). Based on this possibility of integration, allocation recommendations can be derived (Section 2.5) which can be finally transferred into an allocation decision (Section 3.0).
2.1 Usage of a heuristic method

Nowadays, many manufacturing industries are confronted with large variety in jobs and activities whose processing can be very complex to coordinate or schedule. In practice, the determination of optimal schedules normally leads to NP-hard problems in the complexity theoretical sense, for which no efficient algorithms are known [3]. Nevertheless the theoretically optimal schedule has mostly only a short time of validity [5]. Considering the cost-benefit calculation, it is advisable to use a heuristic method generating an approximately optimal schedule in appropriate time.

2.2 The necessity for integration of vagueness

The considered input variables and parameters in scheduling – such as times, lengths of times, quantities and restrictions – usually possess an inherent vagueness [5]. Often, sharpened data is not available or can only be expensively acquired. In addition, dependences between relevant variables are only known approximately [2]. As a rule, there is a continuous transition between permissible and non-permissible conditions [8]. Frequently this fact is ignored. Instead vague data or conditions are often sharpened artificially. However, artificial sharpening of data or conditions should usually be advised against. An artificial sharpening leads sometimes to a distorted image of the reality. In the worst case this leads even to a complete loss of reality [6]. Since it is closer to reality, the consideration of vague information is better than the consideration of artificial sharpened information.

As logical consequence, it is necessary to integrate the vagueness of naturally vague information into the scheduling process.

2.3 Integration of vagueness with fuzzy methods

Naturally vague information conveys in their basic form (but also in a nearly basic form) a more exact conceivable of its accuracy than in an artificially sharpened form. It usually can be assumed that the scheduling results will be more realistic when using information with a form as close to its basic form as possible [8].

A computer-aided interpretation and processing is only attainable if the underlying modeling and processing are both well defined and equally suitable for sharp and for vague information. Vagueness must be processed precisely. For this reason, both the modeling language and the kind of processing must be from a strictly mathematical nature. As a premise, both high comprehensibility and transparency of decision must be ensured [5].

In this context, the fuzzy set theory is particularly suitable. With the fuzzy set theory it is possible to map and precisely process both sharp information and not exact quantifiable information (and vague information respectively) in a uniform way [4].
2.4 Integration of varying, partly vague, basic conditions and objectives

Scheduling processes are subjected to varying, partly vague conditions and objectives. It concerns production internal conditions as well as production external conditions. For instance, job- and resource-specific conditions (production internal conditions) are regarded as well as politically and strategically characterized conditions (production external conditions).

A fundamental approach of the presented method is to provide a possibility to integrate the varying, partly vague, basic conditions directly into the scheduling process and therefore to minimize manual intervention.

For this purpose, it is necessary to interlink the context relevant conditions adequately and to use them as a decision basis whenever decisions must be made in the scheduling process.

The fuzzy theory offers the possibility to put that into practice using fuzzy approximate reasoning methods – as for instance the fuzzy decision support system of Rommeljanger and Eickemeier [9]. With this method, it is possible to map and precisely process sharp information and not exact quantifiable information (and vague information respectively) – such as data, conditions and assessments – in a uniform way [5].

Human decision-making processes can also be integrated into the scheduling process. The feature of human decision-making processes is to get a good solution even if the decision circumstances are complex or poorly structured [10]. That applies also if the underlying information is incomplete, vague or even contradictory [11].

On account of these possibilities, varying, partly vague, basic conditions and objectives can be uniformly integrated into the scheduling process independently of their degree of vagueness. In this way, it is guaranteed that their substantial influence also appears in the scheduling process.

2.5 Usage of resource-specific and resource-comprehensive recommendations for allocations

The allocation of a job is performed by allocation of all its activities to resources – and thereby, the conditions must be considered.

A fundamental idea of the presented method is to keep up a greatest possible degree of flexibility as long as possible to be able to generate an approximately optimal schedule.

The approach is to first determine the resource-specific optimal sequence of all activities to be allocated. In doing so, a detailed perception of the preferred allocation sequence of every resource is gained. Equipped with this information, resource-comprehensive recommendations for allocations can be determined. After all, an explicit allocation decision can be derived from these recommendations.
While determining the recommendations (both the resource-specific recommendations and the resource-comprehensive recommendations), the conditions and objectives described in Section 2.4 must be considered. Since these conditions and objectives can be handled by fuzzy methods in an adequate manner, it is advisable to also determine the recommendations with fuzzy methods.

3 The method for scheduling under vagueness

Based on the fundamental approaches previously discussed, the initial idea for the following new method was developed. The purpose of this method is to get a nearly optimal schedule within an appropriate time considering the vagueness in the scheduling process adequately. The method itself is designed iteratively using a rolling allocation decision mechanism (see figure 1). Since a specific activity is in the following always clearly assigned to a job, a job is an outer wrapper of its activities specifying activity-comprehensive conditions.

![Fig. 1. The scheduling method (Overview)](image-url)
3.1 Generation of a rough temporal relative arrangement of activities

Starting from the jobs and their activities to be allocated, a rough temporal relative arrangement of activities is generated. The generation of this arrangement is based on a fuzzy version of a retrograde scheduling method\(^1\). In literature, a retrograde scheduling method is sometimes also called backward scheduling method.

With this method, the course of scheduling occurs contrary to the technological course; starting from the deadline of a job, the latest possible allocation of its activities is realized\(^2\). Since dates, times, and duration of times are often vague, the retrograde scheduling method is extended to be capable of handling fuzzy representations of these temporal parameters.

The generated rough temporal relative arrangement is used as optimized input for the following time window based selection.

3.2 Time window based selection

Starting from the generated rough temporal relative arrangement of the activities to be scheduled, the activities, which should be considered in a forward-shifted horizon of fixed size, are taken into account by a time window based selection. In this way, a quantitative restriction of the activities observed by the succeeding steps of the method is performed.

This way of proceeding is ostensibly comparable with the load-oriented order release scheduling method, but the concept is different. The load-oriented order release scheduling method is based on the proposition, that a reduction of the average machining time is only possible with a lowering of the average quantity of the prior activity queue; the presented method uses the time window based selection only to reduce the complexity of the succeeding steps. Usually, no complete jobs are represented by the time window based selection of activities. However, manufacturing is primarily job-oriented. For this reason, the list of the selected activities is extended with all unscheduled activities assigned either to the same jobs as the activities picked up by the time window based selection or to only partial allocated jobs of a prior run.

In this way, a list of activities is generated which contains all unscheduled activities of jobs which are referenced either by the time window based selection or by a prior run.

3.3 Job-oriented prioritization of activities

Considering job-specific and comprehensive conditions, all activities of the activity list generated in the previous step are prioritized. Amongst other

\(^{1}\) For detailed information about the retrograde termination method, please see [11] or [1].
things, the activities belonging to important jobs are emphasized in contrast to activities of less important jobs. The prioritization is made by a fuzzy rating method basing on the fuzzy decision support system introduced by Rommelfanger and Eickemeier [9]. Figure 2 shows an example for a job-specific rating.

The priorities assigned to the activities induce a partial order. This partial ordered activity list is used as an initial list for the following activity-orientated resource-specific allocation recommendations.

3.4 Activity-orientated resource-specific recommendations for allocations

Considering the given partial order as much as possible, the activities given by the partial ordered activity list are prioritized resource-specific. In order to provide an evaluation process, the method for the resource-specific allocation recommendation also pays attention to several recently scheduled activities. For this purpose, overlapping resource-specific time windows are used within the rolling planning process. The activities given by the partial ordered activity list and any recently scheduled activities to consider are aggregated to a new activity list which is then prioritized resource-specific by a fuzzy rating method.
If an activity cannot be allocated by a specific resource, it is not a member of the corresponding resource-specific activity list to be prioritized; if an activity can be allocated by several resources it is a member of all corresponding activity lists but usually with different priorities depending on the specific resource. Thereby, the resource-specific situation and conditions are considered as well as comprehensive conditions, hard restrictions and objectives. In doing so, a detailed perception of the preferred allocation sequence of every resource is gained. In this way, resource-specific allocation recommendations can be derived. Equipped with this information, an optimized resource-comprehensive recommendation for allocations can be determined.

3.5 Resource-comprehensive recommendations for allocations

From the resource-comprehensive viewpoint the resource-specific allocation recommendations generated in the last step are not necessarily redundancy-free. The corresponding ordered lists may contain activities which are elements of above one of these lists. Since every activity must be allocated at most one time, a method for redundancy removal is accomplished. Thereby, the consideration of the outer conditions (the strategic conditions in particular) is guaranteed by a fuzzy rating method. In order to achieve a preferably balanced utilization simultaneously, a rolling allocation rating process is employed, which use resource-specific time windows. This rating process will be repeated until no changes or no more significant changes will occur. In doing so, resource-comprehensive recommendations for an allocation are derived for every resource. These recommendations are limited by the resource-specific sliding time windows.

3.6 Allocation and Continuation

The resource-comprehensive allocation recommendations determined in the last step are transformed to allocation determinations for the considered activities. Subsequently, the allocations are performed. Afterwards, all activities that are not allocated are brought into a further scheduling process again. Thereby, all allocated activities are no longer considered in the further scheduling process; if all activities of a job are allocated, this applies also to the corresponding job. In this way, the final schedule containing all activities and jobs is constructed step-by-step.

4 Summary

In this paper, a new method was presented, which integrates the vagueness of naturally vague information in specified shape into the scheduling process considering varying, partly vague, basic conditions and conditions. It was shown how it is possible to integrate that important, but usually hardly
used, source of information using the fuzzy theory and the techniques developed from it. It was also shown the possibility of the integration of human decision and human assessment processes into the scheduling process. By the conscious use of vague information and the avoidance of over specification, even a complexity reduction can be achieved \cite{6}. For not going beyond the scope of this paper, the approach of self-organizing activities \cite{4} was not considered.

References

1. Adam, D. (1992) Retrograde Terminierung: Ein Verfahren zur Fertigungsteuerung bei diskontinuierlichem Materialfluss oder vernetzter Fertigung. In: Adam D. (ed): Fertigungssteuerung – Grundlagen und Systeme. Volume 38/39. Wiesbaden, pp 245–262.
2. Borgelt, C.; Kruse, R. (2001) Unsicherheit und Vagheit: Begriffe, Methoden, Forschungsthemen. In: KI, Künstliche Intelligenz 3/01. Arendtap, Bremen, pp 18–24
3. Brucker, P. (2001) Scheduling Algorithms. 3rd edn. Springer, Berlin Heidelberg New York
4. Eiden, W.A. (2003) Prioritätengesteuertes Scheduling auf Basis eines multi-kriteriellen Fuzzy-Bewertungsverfahrens. Technical Report. Darmstadt University of Technology, Darmstadt.
5. Eiden, W.A. (2003) Flexibles Scheduling auf Basis von Fuzzy-Technologien. In: Geldermann, J.; Rommelfanger, H. (eds): Einsatz von Fuzzy-Sets, Neuronalen Netzen und Künstlicher Intelligenz in industrieller Produktion und Umweltforschung. Fortschritt-Berichte 10/725. VDI, Düsseldorf, pp 70–84
6. Heitmann, C. (2002) Beurteilung der Bestandsfestigkeit von Unternehmen mit Neuro-Fuzzy. PhD Thesis. Peter Lang, Frankfurt am Main
7. Nebl, T. (2002) Production Management. Oldenbourg, München Wien
8. Rausch, P. (1999) HIPROFIT – Ein Konzept zur Unterstützung der hierarchischen Produktionsplanung mittels Fuzzy-Clusteranalysen und unscharfer LP-Tools. PhD Thesis. Peter Lang, Frankfurt am Main
9. Rommelfanger, H.; Eickemeier, S. (2002) Entscheidungstheorie – Klassische Konzepte und Fuzzy-Erweiterungen. Springer, Berlin Heidelberg.
10. Schwab, J. (1999) Logistisches Störungsmanagement. 44th International Scientific Colloquium. Technical University of Ilmenau, Ilmenau
11. Sibbel, R. (1998) Fuzzy-Logik in der Fertigungssteuerung am Beispiel der retrograden Terminierung. LIT Verlag Dr. Wilhelm Hopf, Münster