Production scheduling with discrete and renewable additional resources

K Kalinowski[1], **C Grabowik**[1], **I Paprocka**[1] **and W Kempa**[2]
[1]Silesian University of Technology, The Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A Str., 44-100, Gliwice, Poland
[2]Silesian University of Technology, Faculty of Applied Mathematics, Institute of Mathematics, Konarskiego 23A Str., 44-100, Gliwice, Poland

E-mail: krzysztof.kalinowski@polsl.pl

Abstract. In this paper an approach to planning of additional resources when scheduling operations are discussed. The considered resources are assumed to be discrete and renewable. In most research in scheduling domain, the basic and often the only type of regarded resources is a workstation. It can be understood as a machine, a device or even as a separated space on the shop floor. In many cases, during the detailed scheduling of operations the need of using more than one resource, required for its implementation, can be indicated. Resource requirements for an operation may relate to different resources or resources of the same type. Additional resources are most often referred to these human resources, tools or equipment, for which the limited availability in the manufacturing system may have an influence on the execution dates of some operations. In the paper the concept of the division into basic and additional resources and their planning method was shown. A situation in which sets of basic and additional resources are not separable – the same additional resource may be a basic resource for another operation is also considered. Scheduling of operations, including greater amount of resources can cause many difficulties, depending on whether the resource is involved in the entire time of operation, only in the selected part(s) of operation (e.g. as auxiliary staff at setup time) or cyclic – e.g. when an operator supports more than one machine, or supervises the execution of several operations. For this reason the dates and work times of resources participation in the operation can be different. Presented issues are crucial when modelling of production scheduling environment and designing of structures for the purpose of scheduling software development.

1. Introduction

Formulating the problem of scheduling it is necessary to define the production resources first. The role of the decision maker at this stage is the proper selection of resources, which are directly involved in the execution of orders, and determination of the value of their parameters. The set of resources can be expanded iteratively, as a result of the feedback for further stages of the process of feasible schedule construction. This is due to the fact that production orders are specifying at the later stages of the scheduling, and that the decision-maker initially may not be sure which of the resources will be used for their realization. Modifications in the set of resources may also be associated with the production flow simulations concerning production capacity, the potential development of infrastructure and investment profitability.

The general classification of production resources distinguishes three types: renewable, non-renewable and doubly constrained. Renewable resource is a resource that after the completion of one task can be load by the next one. Examples of this type of resources are machines, workers, tools etc. Limitations associated with the renewable resource concern the scope of its usage, e.g. capacity or availability at the given period of time. In such kind of system resources the number of resource units available at the every moment is usually limited. Non-renewable resources are not subject to regeneration process, and related constraints apply to their consumption. For a non-renewable resource its global quantity is mostly limited. Examples of non-renewable resources are the raw materials, funds or energy. In a production system doubly constrained resources may also be considered – for which both usage and consumption are limited. In this case limited availability at any given time, and total consumption are calculated. Double-limited resource can be e.g. energy (a medium) with limited power allocation and total consumption or funds, if the total capital of the entire project is defined and which is assigned to subsequent periods in a certain amount.

Scheduling problems, which take into account the limited availability of resources, are called Resource Constrained Scheduling Problems (RCSP) [1, 2, 3, 4]. In scheduling of manufacturing systems, in planning of activities the methods from the area of Resource Constrained Project Scheduling Problem (RCPSP) can also be used [1, 5].

From the scheduling point of view an important feature of resources is divisibility, according to which resources are distinguished discrete and continuous [6, 7]. Discrete resources are planned at fixed intervals and, in the planning period, they have a finite number of available and indivisible units of time to be used for tasks execution. Unlike the above, tasks can be assigned to the continuous resource at any time. Adoption of relatively small values of time unit and assumptions about considering the resources as a discrete, in fact, does not limit the availability of the resource and simplifies the planning of their work [8, 9, 10, 11].

In the rest of the paper only renewable and discreet type of resources are handled. The omission of non-renewable and double constrained resources has its justification in the practical problems of operation of manufacturing systems, among which the availability of positions, human resources, tools and accessories is essential for production planning.

2. Production resources

In most researches primary and often the only type of resource is a machine. A "machine" in this case can be understood as a literally machine but also as any kind of workstation, processor, device, workbench, a separate space, etc. In manufacturing systems, with a large number of resources, as a single resource can also be considered a production cell of a higher level, i.e. section, workcenter or production line, division, department or production plant in a specific location [12,13,14]. In this case, a schedule can be made in a hierarchical manner, by scheduling of higher level cells first, and then, more detailed, at lower level cells.

The production system is described by a set of resources. In a situation when some operations require more than one resource the set of resources $S=\{S_i, i=1,\ldots,m\}$ into two, not necessarily disjoint, sets $S = M \cup R$, including the main resources $M=\{M_a, a=1,\ldots,mm\}$ and additional resources $R = \{R_e, e=1,\ldots,mr\}$; where mm is the number of main resources, mr - the number of additional resources, and m - the number of all the resources, with relationship $m \leq mm + mr$.

In order to improve the process of scheduling of alternative resources - resource groups can be defined. $GRz = \{GRz_s, s = 0,\ldots,mg\}$, where GRz is a set of resources groups, $mg \geq 0$. A resource group indicates set of resources that can perform the selected operation or group of operations. The preference of choice (qualifications degree) of a i-th resource in the s-th group is expressed by the priority (weight) wzi,s. Resource membership of different groups represents the range of possibilities for its use, e.g. universality of production means, qualifications and skill level of the workers.

The production resource S_i (renewable, discrete) is described by:

$$S_i = (c_i, kz_i, Lgz_i, Ka_b) \quad (1)$$

where: c_i – the capacity of i-th resource, kz_i – the unit cost, Lgz_i – the list of resource groups, which include the i-th resource, Ka_b – b-th calendar, specifying the availability of the resource.

The resource capacity c_i refers to efficiency, and determines the maximum number of possible tasks, concurrently performed in the resource ($c_i \geq 1$). Resource with a capacity greater than 1 can process more tasks simultaneously. That resource can be treated as a set of resources with c = 1, assuming additional restrictions related to the synchronous loading/unloading, technological similarity etc. Unit cost of resource kz_i is a parameter used in calculation of the order cost in a given production route. List of groups of Lgz_i determines the ability to perform a given operation or group of operations, with the qualification degree expressed by priority. Membership of i-th resource is defined by resource list $Lgz_i \subset GRz$. The working time calendar (Ka_b) determines the availability of the resource for performing assigned operations. Resources in the production system work according to arbitrary generated calendars. The calendar is independent of the resource but resources can use the same calendar. The set Ka determines the system-defined calendars, $Ka = \{Ka_b, b=1,\ldots,mk\}$, where mk is the number of defined calendars. Working time calendar contains periods of availability $Ka_b = \{Od_{b,d}, d=1,\ldots,md_b\}$, where md_b is the number of availability periods in the b-th calendar. Each period is determined by the start date and finish date, $Od_{b,d} = (trd_{b,d}, tzd_{b,d})$.

3. Generation of calendar

Siemens Calendar time as the list of availability periods is generated from a set of calendar periods $Ok_b = \{Ok_{b,c}, c=1,\ldots,mc_b\}$, where mc_b represents the number of calendar periods defined in the b-this calendar. The calendar period is described by:

$$Ok_{b,c} = (tro_{b,c}, tzo_{b,c}, dost_{b,c}, cykl_{b,c}, typ_{b,c}), \tag{2}$$

where: $tro_{b,c}$ – starting date of the c-th calendar, $tzo_{b,c}$ – finishing date, $dost_{b,c}$ – availability of a resource, {available, unavailable},$cykl_{b,c}$ – periodicity, { $cykl_{b,c} = 0$ - non-cyclic, $cykl_{b,c} > 0$ - cyclic}, $typ_{b,c}$ – category of period {work, failure, maintenance, overtime, ...}.

On the basis of defined parameters of each period is assigned to one of four sets: cyclic periods of availability COD_b, cyclic periods of unavailability CON_b, non-cyclic periods of availability, NOD_b or non-cyclic periods of unavailability NON_b. The identification and aggregation of these periods enables creating the availability periods of a calendar (figure 1):

$$Ka_b = COD_b \setminus CON_b \cup NOD_b \setminus NON_b \tag{3}$$

4. Operations

The manufacturing process can be considered by the set of operations $P_k = \{O_{k,g}, g=1,\ldots,no_k\}$, where no_k is the number of operations in the k-th process. An operation $O_{k,g}$ is described by:

$$O_{k,g} = (Lwz_{k,g}, pre_{k,g}, re_{k,g}), \tag{4}$$

where: $Lwz_{k,g}$ – the list of resources requirements, $pre_{k,g}$ – the possibility of preemption, $re_{k,g}$ – the resumability (all applies to g-th operation in the k-th process).

The list of resources requirements ($Lwz_{k,g}$) determines the main and additional resources required for the operation executing. Alternative operations differ in this configuration of the required resources and are used for creating different routes of processes [15, 16, 17]. It was assumed that dates and work times of additional resources in the operation can be different (figure 2) so the list consists of set $Lwz_{k,g} = \{RR_{k,g,h}\}$, where $RR_{k,g,h}$ is a h-th requirement of $O_{k,g}$, and is described by:

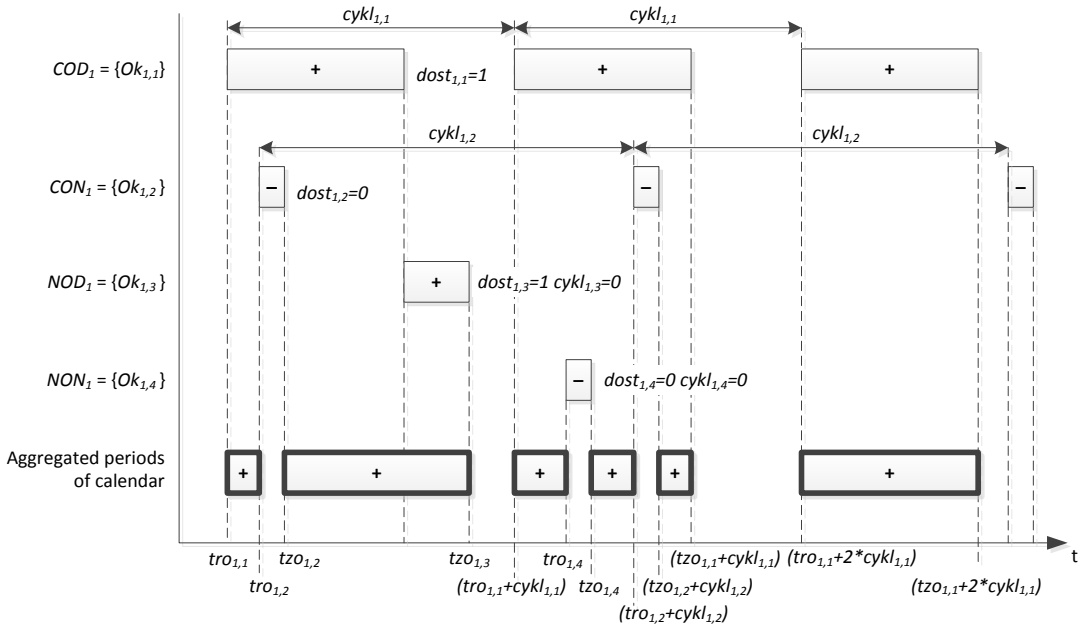

Figure 1. Construction of the resource work calendar.

$$RR_{k,g,h} = (So_{k,g,h}, Ls_{k,g,h}, cor_{k,g,h}, tj_{k,g,h}, tpz_{k,g,h}, ko_{k,g,h}), \quad (5)$$

where $So_{k,g}$ is a subset of the group of resources or specific resources required in g-th operation in the k-th process, $So_{k,g} \subset S$, $Ls_{k,g}$ – the list of quantitative requirements of particular resources in $So_{k,g}$, $cor_{k,g,h}$, - start date correction, $tj_{k,g,h}$ – the operation time, $tpz_{k,g,h}$ – the setup time, $ko_{k,g,h}$ – the cost.

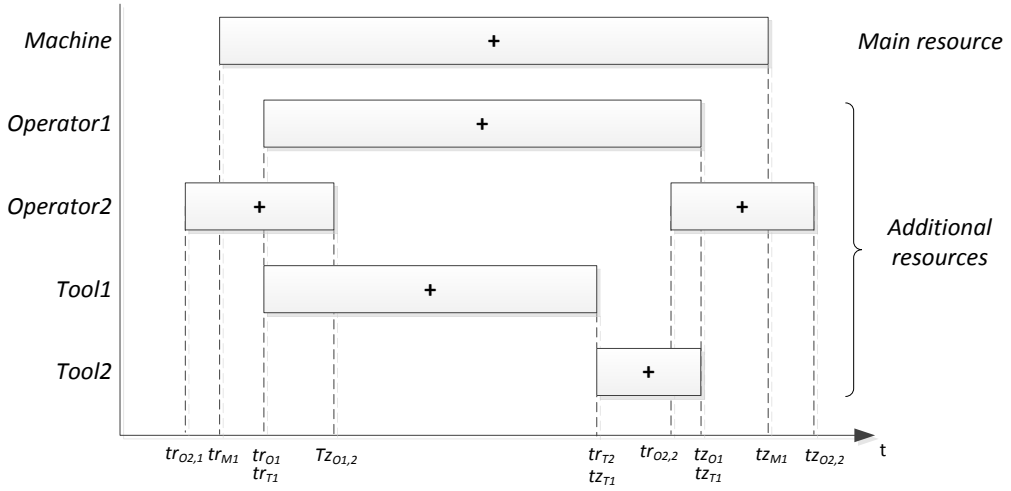

Figure 2. Resources requirements of an operation.

The setup time ($tpz_{k,g}$) can be fixed or variable, depending on the previous operation in the schedule. Taking into account the variable setup times allows precise scheduling of workstations, which setup times largely depends on the number of exchanged tools (if the capacity of tools magazine

is not sufficient). This also allows minimizing setup times by sequencing of operations with similar tools requirements. The value of operations cost ($ko_{k,g}$) is used for calculation of the total cost of the given production order route. Preemption ($pre_{k,g}$) determines the admissibility of breaking execution of an operation, in order to carry out the other, e.g. with a higher priority. Resumability ($re_{k,g}$) determines if the operation may be resumed after the resource unavailability, resulting from the breakdown, calendar etc.

5. The method of operations scheduling with additional resources

The proposed method applies to operation scheduling with additional resources and is an extension of the method of scheduling presented in [17, 18]. Stages of the proposed method are presented in figure 3.

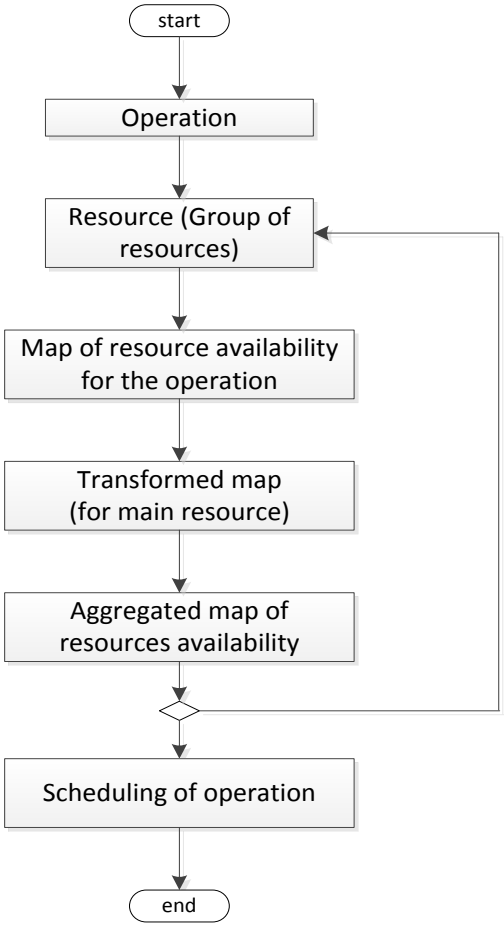

Figure 3. The prepartion to operation scheduling in case of additional resources.

At the first stage the identification of all the resources of operation to scheduling stored in $Lwz_{k,g}$ – the list of resources requirements is done. Then the procedure iteratively considers time constraints of each resource, starting from the main resource. Next, the map of resource(s) availability is created. If the item in the list indicates the resource group and more resources from the group – indicated is only the availability of required amount of resources. As was shown in figure 2 the working times of individual resources may vary from the time of main resource. In this case, particular availability maps should be transformed according to defined differences in dates and times of their work. Aggregation of all transformed maps of required resources availability enables scheduling of given operation.

6. Summary

Additional resources scheduling is one of the fundamental problems in most real manufacturing systems. Discussion is limited to systems with discrete production flow and considered resources are renewable (machines, tools, human resources). The paper presents the model of the production system and the general method for scheduling operations, as an extension of manufacturing system scheduling procedure, if more than one resource at the same time is required. The most important characteristics of resources, including time calendars are described. Such functionality greatly increases the usefulness of scheduling system for practical applications.

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