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production flow scheduling
dispatching rule, constraints satisfaction
immune algorithm

Bożena SKOŁUD[1]

APPROACHES TO THE PRODUCTION FLOW SCHEDULING AND CONTROL

In the paper different methods of production order scheduling and control that are elaborated by the author and the team are presented. The history starts from the dispatching rules and goes to the distributed control by the local dispatching rule allocation and application them in the software (KbRS, SWZ, etc). In the next stage of the paper the discussion goes to the integration of these approaches. Last stage of the paper the artificial intelligence (Immune Algorithm) application for optimization of the schedule under the condition that any permissible solution is attainable is proposed. This application is only the part of the integrated system and is utilized as a tool for the solution improvement.

1. INTRODUCTION

Nowadays, a high degree of flexibility, quick response time for customer expectation as well as the fact that enterprises are oriented for fulfilling the market and customers demands is observed.

A company management requires from one hand a constantly high level of the existing resources utilization and from the other hand fulfilling short delivery time and minimise stocks. The tendency of shortening the product life cycle by the producer because of fear of the concurrency on the market is also observed. That's why the response time and time for decision making is shorter and shorter.

This situation results from the new strategic point of view, in the modern market (mainly in Europe). According to the ManuFuture platform, following drivers of changes are important [5]:

- competition,
- the life cycle shortening,
- socio-economic environment,
- regulatory climate.

Reaction for such drivers is seen as :

- new addend value products and services,
- new business models,

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[1] Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Silesian University of Technology

- new advances industrial engineering,
- new emerging manufacturing sciences and technologies,
- transformation of existing research and development sectors.

In this context few original methods and software elaborated by the author and the team, supporting the decision making process in the area of production flow (planning stage, scheduling and control stages) are presented below.

2. SCHEDULING

2.1. PRODUCTION ORDER VERIFICATION

In order to verify whether a given work order can be processed in a production system a constraint-propagation-based approach has been implemented. The underlying idea assumes the examination of conditions encompassing a relationship balance between particular constraints and production orders and/or production system parameters. The concept of the constraint propagation has been implemented in the computer aided production planning software package System of Production Order Verification – SWZv3 that is available in the Internet (**http://swz.of.pl**) [6] The system supports decision-making in the course of the dispatching rules allocation, i.e. in the case of production flow planning and a control. The SWZ functions in an interactive mode. Basing on the given input data the package helps to determine parameters of the system operation, production and delivery batch size, delivery periods, the rate of machine utilisation, realization time, system efficiency etc. System also generates the control procedure and integrates the production planning and control stage. In the mentioned system of repetitive production the steady state should be preceded by the starting-up phase, in order not to lead a system into undesirable situations, e.g. deadlock appearance or synchronisation with an undesirable cycle.

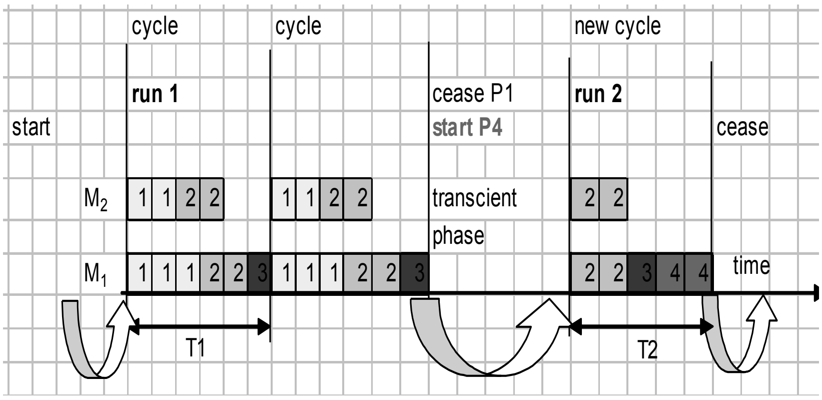

Fig. 1. Transient phases in the multi assortment repetitive production system

The problem of the system synchronisation motivates the consideration of construction of dispatching rules allocated locally to the system resources, called “meta-rule” [3,4].

META RULE {[starting-up rule], [dispatching rule], [cease rule]}

The first part of the meta rule is the starting-up rule, which is executed once. Its execution assures the synchronisation of the system with desirable cycle. The dispatching rule is executed repetitively and it guarantees steady-state behaviour of the system. The 3-th part of the rule is the procedure of the production cease, which bring the whole production to the end without deadlock (Fig.1).

2.2. SCHEDULING AND RESCHEDULING

In the production system where production is client oriented one of most difficult problem is to create the schedule and its modification in case of disturbances appearance. For that reason the knowledge base rescheduling system (KbRS) which is a prototype of the expert system was elaborated by Kalinowski [2]. The KbRS create the schedule by allocation dispatching rules such as: first in first out (FIFO), last in first out (LIFO), longest operation time (LOT), shortest delivery period (SDP), etc.

Data base contains knowledge representation of the field of production flow control. Knowledge representation is prescribed by attributes and methods that depend of triple (scheduling algorithm, reaction type and validation criteria).

Data of production system structure, production processes, and technological information are introduced into the system directly from the data base or by the program interface.

As was mentioned the system creates schedule according to priority rules.

Production flow analysis (schedule validation, and choosing of the new one) is assisted by the graphical interface (simulator). This approach is recommended for changeable, single-batch production.

2.3. SYSTEMS INTEGRATION

As was mentioned before basic problem is precise production time estimation. For that reason the integration of KbRS and SWZ is proposed.

Schedules for transient phases are created for given in the dispatching rules operations sequences. The input data for the KbRS are prepared in the SWZ. The schedule for both starting and cease phases is created by the recurrence algorithm [4] which is implemented in KbRS [3].

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For all machines
For first operation of the dispatching rule  allocated to the machine
Execute function „OST” Operation starting time
Function „OST”
If operation starting time < ending operation time of previous operation in the rule than replace
operation starting time = ending operation time of previous operation
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If next operation in the production route exists than for this (successive) one

If operation starting time of a successive one in the production route = ending operation time of the previous operation

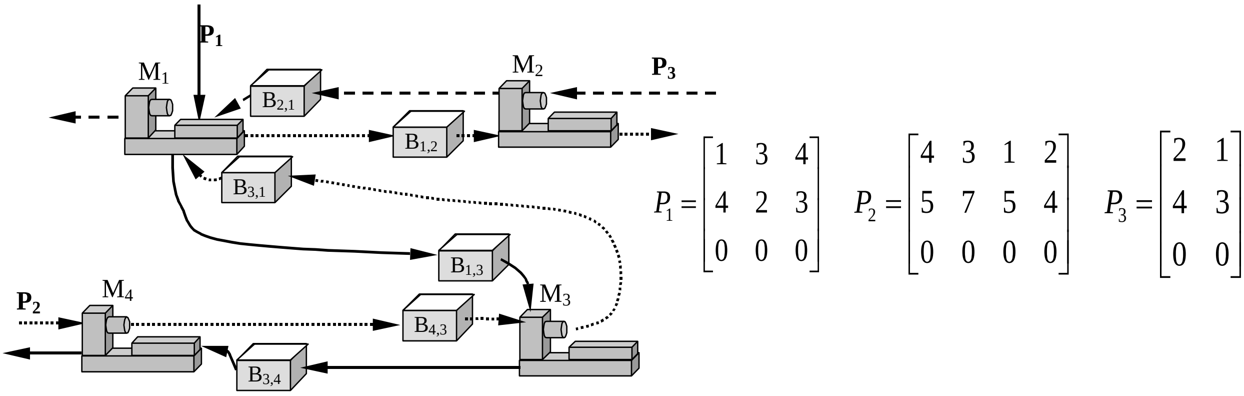
1. *Do: operation starting time of operation successive in the production route = ending operation time of previous operation*
2. *Execute "OST"*

If next operation in the dispatching rule exists than for successive one execute OST

Applied algorithms enable analysis of efficiency of the operation sequencing on resources, stands, production route modification and another indexes. SWZ, KbRS and simulation package (Enterprise Dynamics) integration enables rapid time estimation of starting and cease phases for multiassortment repetitive production as well as simulation and verification of estimated control procedures. Moreover 3D visualization of production system is easy to do. Automatic creation of the simulating models may be used for analysis of a timetable of transportation means, interoperation's buffers localization, detection of collisions, and experiments of the system functioning in case of machine breakdown, verification of estimating results, etc.

2.4. ILLUSTRATIVE EXAMPLE

Let us consider the manufacturing system composed of 4 machines. The following processes P1, P2, P3 (described by matrices) should be introduced to the system (Fig. 2).
The first row of each matrix contains the number of the machines, the second row contains operation times and the third one pre-set times.
Data about the system and processes are put to the SWZ, which allows to quick answer the question "what dispatching rule should be allocated to the resources?". Dispatching rules determined by SWZ are R1, R2, R3 and R4, they are allocated to machines M1, ..., M4, respectively (see Fig. 3) and assuring the deadlock-free functioning of the system.

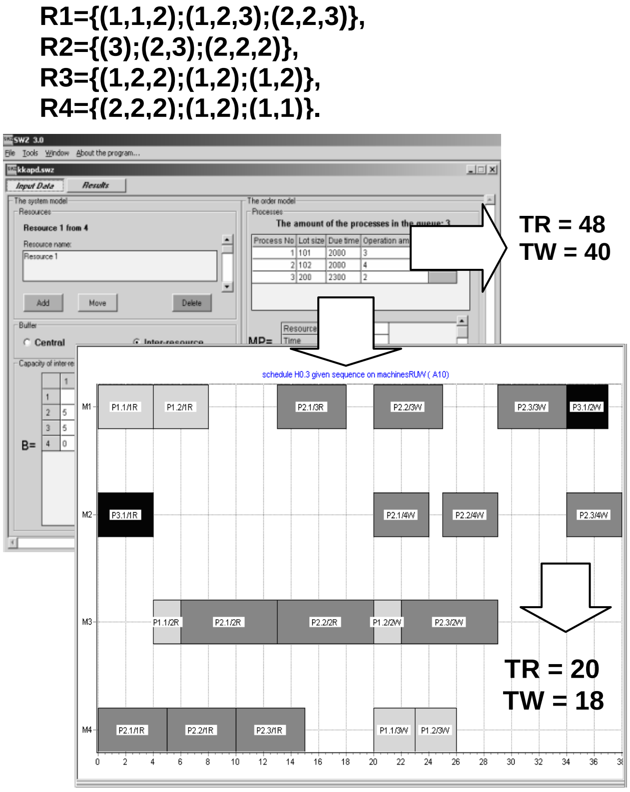


$$P_1 = \begin{bmatrix} 1 & 3 & 4 \\ 4 & 2 & 3 \\ 0 & 0 & 0 \end{bmatrix} \quad P_2 = \begin{bmatrix} 4 & 3 & 1 & 2 \\ 5 & 7 & 5 & 4 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad P_3 = \begin{bmatrix} 2 & 1 \\ 4 & 3 \\ 0 & 0 \end{bmatrix}$$

Fig. 2. System specification

Realization time of the repetitive period that is generated by SWZ is equal 588 time unit and starting and cease phase for the most unprofitable variant are respectively: $TR_{max} = 48$ and $TW_{max} = 40$ time units.

In the next step the SWZ output data (resources, processes dispatching rules), are introduced to the KbRS which generates the schedule for starting up and cease phase using recurrence algorithm. Realization time of that phase are respectively TR = 20, TW = 18 time unit



Resource 1 from 4

Resource name: Resource 1

The amount of the processes in the queue: 3

Process No	Lot size	Due time	Operation am
1	101	2000	3
2	102	2000	4
3	200	2300	2

	1
1	
2	5
3	5
4	0

Fig. 3. SWZ and KbRS systems integration; R1, R2; R3; R4 dispatching rules; TR starting phase, TW – termination phase

3. IMMUNE ALGORITHM FOR SCHEDULING

In this chapter of the paper a method which enable to improve admissible solution received using SWZ or KbRS is presented.

In optimizing the performance of a system, it is difficult to reach compromise between multiple objectives. Optimizing one from objective function usually leads to deterioration of others. No method has been found for this time to solve the multi objective (to minimize a makespan, to minimize a total tardiness, to minimize a total flow time and to minimize a total idle time of machines) job shop scheduling problem in polynomial time. Recently, Immune Algorithms (IA) seem to receive large attention in literature, since they have been proved as versatile and effective optimization technique. In this chapter a multi-objective meta-heuristic algorithm based on immunology to solve the job shop scheduling problem is presented.

IA that are applied for optimization of the schedule. It is assumed that any permissible solution is attainable. It means that AI application is only the part of the integrated system can be part of SWZ or KbRS and is utilized as a tool for the solution improvement.

3.1. BASIS OF IMMUNE ALGORITHM

In IAs the pathogen represents scalar objective function, and antibodies correspond to solutions of the problem. IAs applied in scheduling problem with single objectives function, have ability to maintain balance between diversity of solutions and time for obtaining a local optimum [7]. In proposed IA two stages are distinguished. First one corresponds to the exogenous activation of the immune system. In this stage the temperature parameter plays the most important role. Second stage corresponds to the endogenous activation. Here antibodies are trained and their stimulation degrees to the pathogen are taken into account.

In IA each gene represents one job. Genes are coded in DNA library. The chromosome represents a feasible solution. The length of antibody's chromosome equals number of all jobs executed in the job shop. The position of gene in the chromosome indicates job's priority.

The immune searching process starts with generating initial population of antibodies at random. The size of population depends on the number of objective functions. In process of pathogen affecting a vertebrates' body, the temperature of the body rises as well as a number of pathogens and their ability to destroy the body. In response to the invasion process lymphocytes release higher number of antibodies. This phenomenon is also used in IA. Only those lymphocytes that recognize the pathogen secrets antibodies.

In IA weights in scalar function are randomly selected on times and each time quality of initial population is computed. If the quality of new population is better the weights are memorized. For the best vector of weights (promising search direction), the immune search is started (Fig. 3). Proposed strategy leads to eliminate the decision maker interaction. For

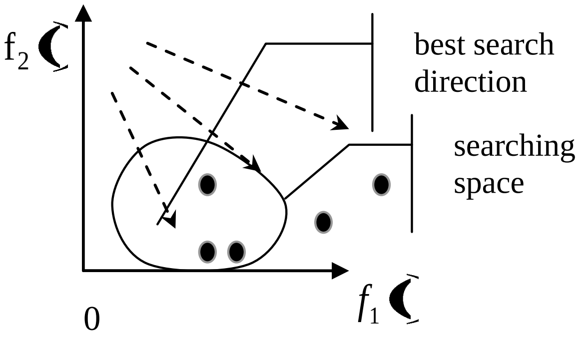


Fig. 3. Strategy of searching space choosing

each generation the best solution is copied to an immune memory. The superior solution from the memorized solutions is an optimal or near to optimal for given search direction. The advantage of searching for best randomly selected vector of objective weights is reduction the computational time.

3.2. EVOLUTION PROCESS

The endogenous system starts with creating sub-populations that nest evolve separately. This idea of dividing the initial population into sub-populations, where each of sub-population deals with one objective is similar to the one presented in [1]. Number of sub-populations is equal (K+1) the number of objective functions. Additional sub-population (K+1)-th is foreseen to evolve antibodies to the pathogens according to the scalar fitness function. Process of antibodies' selection to create matting pool is random. In reproduction procedure crossover operator is applied. All chromosomes undergo crossover operation (probability=1) in order to assure the complete exploration of the solution space. In elite selection procedure, from pair consists of one parent and one offspring, better individual with higher value of objective function survives.

Better individuals undergo mutation operation and also the elite selection procedure is carried out. (K+1)-th sub-population differs from others in reproduction procedure. In this case a hypermutation is used for generating new offspring. Number of hypermutation points depends on the affinity of antibody to the pathogen, which corresponds to the quality of schedule.

Sometimes, in the immune system, if a disease is very strong, simple antibody is not able to neutralize the pathogen. The pathogen is only destroyed with common power of certain number of antibodies that are focused on them. Antibodies recognizing the pathogen represent solutions that are in neighborhood in solutions space. The degree of stimulation between the p_k and p_{k+1} belonging to neighborhood $N(p_k)$ is counted using the Hamming distance. The stimulation threshold is one of the input data the decision maker assumes. The higher stimulation threshold is the longer Hamming distance is. In the strategy of neighborhood reduction one from the same antibodies survives. It helps to maintain the high diversity of solutions.

3.3. CASE STUDY

Let us consider the manufacturing system composed of four resources. Seven processes should be introduced in the system. Due date $T_{z,i}$ of *i-th* production job is determined and described in a matrix of production orders' due dates *MD* (1). MP (2) and MT (3) matrices describe process. The MP represents processes routes, whilst the MT corresponds to operation times. A row vector of both matrixes states as operations of the process, a column of matrixes represents the machine.

The problem is to found a schedule that minimizes the makespan, the total tardiness, the total idle time of machines and minimizes the total flow time.

$$MD = \left[30,40,25,40,25,60,70\right] \tag{1}$$

$$MP = \begin{bmatrix} 1 & 2 & 3 & 4 \\ 3 & 2 & 1 & 4 \\ 4 & 2 & 1 & 3 \\ 3 & 2 & 4 & 1 \\ 2 & 3 & 4 & 1 \\ 3 & 2 & 4 & 1 \\ 2 & 4 & 3 & 1 \end{bmatrix} \qquad MT = \begin{bmatrix} 7 & 6 & 5 & 4 \\ 3 & 2 & 4 & 3 \\ 5 & 6 & 4 & 3 \\ 5 & 1 & 2 & 7 \\ 5 & 3 & 1 & 7 \\ 5 & 4 & 9 & 2 \\ 6 & 3 & 8 & 2 \end{bmatrix} \tag{2, 3}$$

The number of the initial population equals the number of objective functions multiplied by 10. Two objective functions: to minimize makespan and to minimize total flowtime applied to IA as it is difficult to demonstrate results for the number of objectives more than two. In the algorithm crossover and the switching mutation were used with the probabilities assumed as 1. The stimulation threshold is equal 2. The temperature threshold equals 0.8. The IA finishes searching after 40 iteration. In this case the IA was run 6 times, and best solutions can be fount in the initial stage of the algorithm. Best search direction was [0.6, 0.4]. The quality of the best schedule previously found was equal 105.8 whilst the quality of one later found was equal 104.4. Fig. 5 represents final antibodies' population with the superior solution. The Gantt chart of best schedule is presented in Fig.4.

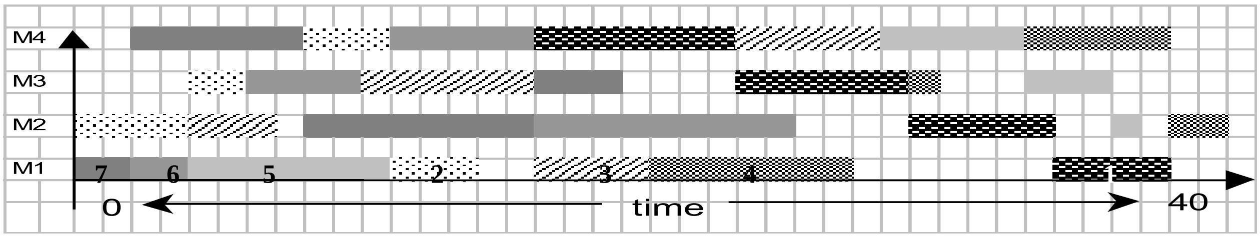


Fig. 4. The Gantt chart of the best solution

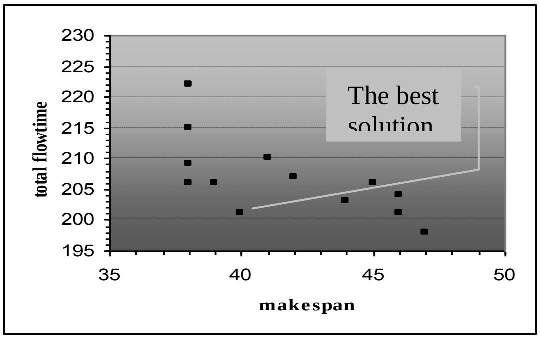


Fig. 5. Population quality

The IA has found solutions in reasonable amount of time. The main advantage of the algorithm is computation time reduction. Promising direction searching enables a faster search to reach the best schedule. Best schedules are found in the initial stages of the IA. The equilibrium between space exploration and solutions exploitation is kept. The decision maker is released from obligation to select the best solution.

4. CONCLUSION

In the paper different approaches to the problem of production tasks scheduling are presented. The integration of presented approach is suggested in order to assume better solution. The approach based on IA application for optimisation is given. The IA algorithm can be used as a second step of searching solution. First SWZ or KbRS can be applied for confirmation that admissible solution exists and that optimisation make sense than

As a next step of research full automation of the decision making in the area of scheduling and integration them with simulation software in order to visualise received solution is foreseen.

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