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Production Scheduling in Flexible Manufacturing Systems: A State of the Art Survey

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Abstract **– The complexity of production scheduling problem concerned the attention of worldwide researchers and over time different approaches were proposed in order to solve in an optimum manner this problem. This paper proposes a survey over the latest researches on this field. A complete analysis over the latest published paper in this field is presented and the most popular scheduling system available at international filed are analyzed. The modern approaches include the utilization of hybrid algorithms in order to optimally solve the production scheduling problem, and the most popular scheduling systems that are implemented in real flexible manufacturing systems must be well designed and extremely complex in order to satisfy all the market demands. Comparisons are made considering various criteria and conclusions are presented.**

Keywords - Flexible Manufacturing Systems, Production Scheduling, Artificial Intelligence

I. INTRODUCTION

Scheduling problem consist in the identification of methods for organizing the operations set execution under certain constraints of time (total time of execution, operations precedence constraints, etc.) as well as capacity constraints in resources [1].

The scheduling result is represented by the description of the resource allocation for each time value and the order of the tasks execution. His purpose is to achieve resource optimization and the minimization of the execution total time.

The conceptual model of a planning system, is introduced by Ghallab in 2004 and can be considered extremely useful because it presents the basic concepts and theoretical restrictions in a simple manner.

A planning system can be formally represented as a 4-tuple $\Sigma = (St, A, E, h)$, where [2]:

- $St = \{st_1, st_2, \dots\}$ is a finite set of states;
- $A = \{a_1, a_2, \dots\}$ is a finite set of actions (operations);
- $E = \{e_1, e_2, \dots\}$ is a finite set of discrete events;
- $h: St\times A \times E \longrightarrow 2^{St}$ is a transition function.

A classical scheduling problem is represented by $P = (st_i, g)$, where st_i is the initial state of the problem and g is a set of requirements that must be fulfilled to satisfy scheduling purposes;

The scheduling problem solution is classically represented by a plan π detailing the action sequence that needed to fulfill the requirements set.

The elements that define a planning problem are [4]:

- A set of resources;
- A set of requirements that must be met and the resources associated with their achievement;
- A set of constraints on resources and actions;
- A function *f* for calculating the cost.

The main objective of scheduling is to optimize the value of the *f* function and to achieve this objective are taken into account several criteria such as [3]:

- The total time required to complete the schedule;
- The biggest delay associated with the proposed schedule;
- The total delays;
- The total cost associated with the plan.

The classical type of scheduling problems can be classified as:

- One Machine Scheduling Problem – OMSP;
- Parallel Machine Scheduling Problem – PMSP
- Flow Shop Scheduling Problem – FSSP
- Job Shop Scheduling Problem – JSSP
- Open Shop Scheduling Problem – OSSP

This article presents an overview on the production scheduling area. The main algorithms and techniques used in this field are synthetized with the modern directions referring to applying artificial intelligence methods or hybrid algorithms into this field. In the last section of this article is presented the state of the art of the scheduling systems available at this point for the production scheduling in flexible manufacturing systems. The considered systems are compared and conclusions are drawn.

II. Flexible Manufacturing Systems

Developing a reliable production system requires consideration of social and economic trends related to the decreased usage of natural resources and raw materials and the increase of competition in international markets.

To meet these new challenges, new production systems will have to meet a number of requirements, such as:

- consumption of raw materials and energy decrease;
- Increasing labor productivity;
- Increasing product reliability;
- Minimize design and manufacturing time;
- Diversification of obtained products;
- Minimizing production cost.

Flexible Manufacturing Systems (FMS) offer a solution to achieve these requirements. Such a system must have the following characteristics [4]:

- Integrability - the property to be integrated into a production system and to be interconnected with other production systems;
- Adequacy - the property to fully exploit the production capacity, with minimal expenses;
- Adaptability - the property to adapt quickly to changing production tasks;
- Dynamic structural - the ability to change the structure of FMS depending on production requirements.

The main goal is to increase resilience to problems along the production line, to increase the equipment workload and to reduce execution time.

Production scheduling problem in a flexible manufacturing system is described by JSSP. This problem is one of the most intractable in the industry and has been included in the category of NP-complex, according to Srinivas and Allada in 2004 [5].

In these circumstances the complexity of production planning problem represents a real challenge for the scientific community and thus a variety of methods have been proposed to solve this problem.

III. Production Scheduling Algorithms: Modern Directions

Production scheduling is an extremely important tool in terms of increased efficiency for using the available resources and reducing waste. The importance of this production process stage went to applying different methods for optimal organization of each step in the operation sequence.

In addition to classical methods enshrined in scheduling, new tools have already been proposed based on other algorithms that provide an optimization of certain terms that characterize the production (total time of execution, the use of machines, optimizing the use of resources, etc.)

Those new approaches are listed below:

- Artificial Intelligence Algorithms (Ant Colony Optimization - ACO [6], Particle Swarm Optimization – PSO [7], Artificial Bee Colony Algorithm – ABC [8], Genetic Algorithms - GA [9]);
- State space search algorithms (Progression Scheduling, Regression Scheduling, Mixt Scheduling) [10];
- Partial Order Planning - POP [11];
- GraphPlan Algorithm [11];
- Decision Tree Method [12];
- PERT Method [13];
- Critical Path Method [14];
- Just in Time Method [15].

In the specific literature, different approaches for solving the production scheduling problem are presented, most of them being based on Artificial Intelligence techniques.

One of the most eloquent examples is shown in Table I. The attention of researchers is concentrated mainly on minimizing the total time involved in the process of production, maximizing machine utilization and minimize waiting times.

TABLE I. ARTIFICIAL INTELIGENCE TECHNIQUES FOR JSSP

Method	Novelties	Reference
PSO	• Minimize the total execution time by scheduling activities for multi-objective model JSSP • Change the formula for calculating the velocity of the particles in the search.	[16]
PSO	• Optimizing planning flexible manufacturing lines by implementing a learning process associated particles.	[17]
PSO	• Minimize the total waiting time for accessing machines; • It is proposed PSO algorithm implementation on two levels (first level is used for rapid evaluation of solutions, and the second continues the search by applying a more accurate assessment strategies.	[18]
PSO	• Minimizing the total time of execution; • Optimizing of available machines selection.	[19]

AG	• The initial population of AG consists of randomly generated solutions; • The solution is then obtained from AG undergone a local search function using a different heuristic	[20]
AG	• Simulation made for a flexible manufacturing system for the routes followed if products are not fixed.	[21]
TS	• Improving how search solutions space by changing the structure and implementation of special filters neighbors.	[22]
ACO	• Change the amount of pheromone based on the occupancy of machines.	[23]
ACO	• Integrating the knowledge base within the ACO algorithm.	[24]
BC	• Minimizing the total time required execution.	[25]

Table II summarizes the latest papers published in the production scheduling field that proposes the utilization of hybrid algorithms in order to combine the advantages offered by the original methods and minimize each ones' disadvantages.

TABLE II. HYBRID TECHNIQUES FOR JSSP

Hybrid Method based on	Novelties	Reference
PSO TS	• A different way of representation of particles in PSO; • Change the particles movement by using TS search space;	[26]
ABC PA	• Combining ABC with a Pareto analysis of partial solutions to identify the most reliable solution;	[27]
AG SA	• At the end of AG execution the resulting solutions will be refined using SA;	[28]
ACO TS	• Propose a planning optimization by selecting neighbors for ACO using TS;	[29]
PSO SA	• Proposed the SA algorithm modification by searching the solution through the search space consisting in PSO generated neighbors;	[30]
PSO SA	• The PSO solutions are optimisez by using SA;	[31]
PSO SA	• Offer another approach by selecting an random number of SA solutions to be a part of PSO algorithm;	[32]
PSO SA	• The intial solution for SA algorithm is generated by using PSO algorithm to optimize the total time required execution;	[33]
PSI AG Kacem allocation scheme	• The initial population of solutions is pseudo-randomly generated first, then modified based on Kacem allocation scheme; • Apply specific AG genetic operators every step of the PSO algorithm;	[34]
AG Local Search	• AG specific genetic operators are modified by adding a local search operator;	[35]
AG PSO	• Proposed to adjust PSO by introducing at every step of algorithms AG specific operators (selection, crossing and mutation);	[36]
PSO Artificial Immune System	• Propose combining local search strategy with PSO mechanisms with adaptation and evaluation strategies offered by Artificial Immune System Algorithm;	[37]
PSO Artificial Immune System	• AIS algorithm is modified by inserting a acceleration search methode based on PSO optimal solution identification;	[38]
AG Local Search	• Integrating a Local Search procedures into AG;	[39]
PSO G&T Algorithm	• Within PSO, after the step of updating the particle position G & T algorithm is applied to identify changes to be made on critical operations;	[40]
SA PSO	• Offer combining the advantages of global search by PSO with the local search by SA;	[41]
PSO SA	• Proposes the integration of SA technique intro the initial population generation of PSO; • At each step of PSO, SA is applied to a randomly selected set of particles;	[42]

IV. DEDICATED PRODUCTION SCHEDULING SYSTEMS. AN OVERVIEW

In this section of the paper there are studied a set of 16 scheduling systems that are used in different areas for production scheduling in real manufacturing systems.

The studied systems are presented below:

- LEKIN® System developed by Stern School of Business (New York) in collaboration with Columbia University was created as an educational tool and it allows modifications into the scheduling algorithms [43];
- AIMMS System proposed by USA Paragon Decision Technology is used both in academic and commercial areas as a decision support tool in the field of resource management, production, predicting market trends etc. [44];

- GSCPS System developed by SIM Technologies China is mainly implemented in the cosmetics industry, the production of electronical compounds and the production of agriculture equipment [45];
- FMSS developed by SIM Technologies China for Cincinnati is used by companies such as: Sunstrand Corporation - producing equipment for aircraft and electrical systems for industrial, PHB Incorporated - producing tools of zinc and aluminum used in various fields, TRW - producing parts automobile [45];
- Tupas PSS is proposed by Tupas Softwares and is applied in USA in the pharmaceutical industry and constructions industry [46];
- Asprova APS is designed by Asprova Corporation Japan and represents a very popular scheduling software solution in Japan (it is used by over 1,000 small and medium enterprises with diverse production activities in the country) [47];
- JobPack Driving Solution developed by SAP is implemented in the pharmaceutical and plastics production field [48];
- IQMS Manufacturing ERP proposed by IQMS Canada is implemented in Nord America and Asia. Areas of industry where this system is already implemented are: automobile production, food production, production of plastics and metal [49];
- PLEX Software System is implemented at international level in the car production and plastics manufacturing [50];
- SeikiSoftware Advanced Manufacturing is the international market leader in the production scheduling on manufacturing systems specialized in steel processing [51];
- Preactor Advanced Planning & Scheduling Software is developed by Siemens and is already implemented in different areas of industry such as car production, production of aircraft equipment, food processing, glass and plastics processing, pharmaceutical and textile industry [52];
- PIMSS (Process Industry Manufacturing Scheduling System) is proposed by MJC^2 and is implemented in different areas of industry such as: food processing, textile production and automotive production [53];
- Demand Solutions Advanced Planning & Scheduling System is implemented at international level in areas such as the food industry, production of medical equipment, production of alcoholic beverages [54];
- Tricorn Systems is widespread in UK in areas such as metals manufacturing, production of precision medical equipment, food processing [55];
- Giraffe Production Systems is implemented at international level and the industrial fields covered by this system are: metal processing, production of construction materials and packaging production [56];
- SEMS® System is proposed by Steelman Software Solutions Inc and his main application field is metal processing [57].

In Table III are highlighted input parameters of the scheduling system that can be set by the human operator through the user interface: SS – the structure of the system (number of cars, the number of transport devices), RMS - the current stock of raw material, SC – the storage capacity to deposits raw materials or finished products, LPLE- the lots of products launched in execution, Mb – the machine breakdowns.

It is noted that the majority of all these features enables modification for the best possible control over the scheduling system.

TABLE III. INPUT PARAMETERS

System name	SS	RMS	SC	LPLE	MB
LEKIN®	X	X	X	X	X
AIMMS	X	X	X		
GSCPS		X	X		
FMSS	X	X	X	X	X
Tupas PSS	X	X	X	X	X
Asprova APS	X	X	X	X	X
JobPac Driving Solution	X	X	X	X	X
IQMS Manufacturing ERP	X	X	X	X	X
PLEX	X	X	X	X	X
SeikiSoftware Advanced Manufacturing	X	X	X	X	X
Preactor Advanced Planning & Scheduling Software	X	X	X	X	X
PIMSS	X	X	X	X	X
Demand Solutions Advanced Planning & Scheduling	X	X	X	X	X
Tricorn Systems	X	X	X	X	X
Giraffe Production Systems		X		X	
SEMS®		X			

Table IV summarizes the facilities for modeling and simulation provided by studied scheduling system, being considered related to the presence of a friendly interface (FF) that does not require additional training of staff to use, modeling in 2D system manufacturing (2DM), presentation Gantt chart of activities (G), information display received from the sensors in the manufacturing system (SI), generate reports (GR) and access to schedules made in the past (SH). These facilities are very important because they allow simple use of the system as well as ease visualization software schedule history.

TABLE IV. MODELING AND SIMULATION FACILITIES

System name	FF	2DM	G	SI	GR	SH
LEKIN®	X		X	X		
AIMMS	X					
GSCPS	X		X		X	
FMSS	X	X	X	X	X	X
Tupas PSS	X		X	X		
Asprova APS	X		X			
JobPac Driving Solution	X		X		X	X
IQMS Manufacturing ERP	X		X		X	X
PLEX	X		X	X	X	X
SeikiSoftware Advanced Manufacturing	X		X		X	X
Preactor Advanced Planning & Scheduling Software	X		X		X	X
PIMSS	X	X	X	X	X	X
Demand Solutions Advanced Planning & Scheduling	X		X	X	X	X
Tricorn Systems	X		X		X	X
Giraffe Production Systems	X		X		X	
SEMS®	X		X		X	

Current trends are reflected by developing complex scheduling systems based on different scheduling techniques (based on IA and not only) that meets increasingly clear market on optimizing manufacturing process, minimizing the total time required in production, using the machines at full capacity, avoiding storage overloading, with the ability to make changes in real time, etc.

Another trend refers to the development of systems as easy to use with a friendly interface, which presents the scheduling results in a manner as easy to interpret (such as Gantt charts). Other facilities offered the studied scheduling systems are: the 2D representation of the manufacturing system, generate reports, store planning history etc.

CONCLUSION

This paper presents a survey on the automated scheduling systems state of the art. The main types of scheduling problems are presented and it is highlighted the fact that JSSP is one of the NP-complex problems in the manufacturing area. This study consists also in the analysis of 16 scheduling systems developed for both academic and commercial environment, applicable in various fields of industry.

It notes that the studied systems are also suitable for application in flexible manufacturing systems for JSS problem, this area being far from exhausted. An optimal scheduling system must provide a friendly user interface, must be adaptable to different production systems, to optimize machines utilization, avoid overloading the available storages and so one. The results of this study are leading to the conclusion that the researches in this area should continue, in the hope of a better scheduling system will be found, that can optimize increasingly more the whole production process.

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