Journal of Machine Enginnering. 12, No. 3, 2012

scheduling, decision making, multicriteria optimisation

Krzysztof KALINOWSKI[1]

MULTISTAGE DECISION MAKING PROCESS OF MULTICRITERIA PRODUCTION SCHEDULING

In this paper the multicriteria optimisation problem in scheduling of discrete manufacturing systems is presented. The proposed method is an extension of work on integrated management system for variable and multiassortment production to order in small and medium-sized enterprises (SMEs) that is developed in the Institute of Automation Processes Engineering and Integrated Manufacturing Systems of Silesian University of Technology. Particular attention was paid to discuss the scheduling system operating conditions in an integrated environment - a system operating in real time. The proposed method indicates different decision-making stages to be taken in scheduling, from defining the problem, determining the structure of the production system, constraints and objective function, up to the generation and evaluation of solutions. The various approaches of decision maker participation in the process of finding the best solution are taken into account: a priori, posteriori and interactive.

1. INTRODUCTION

Production scheduling, according to the decision theory, can be considered as a decision making process of building and rebuilding a schedule for the defined system [21]. Searching a schedule is an optimisation problem, many acceptable solutions can be generated but finally the best one should be selected for implementation. Scheduling in real manufacturing systems is very often difficult not only because of the complex scheduling layout, large amount of constraints but also in most cases more than one evaluation criterion. From the production system it is mostly required to produce quickly, on time and, of course, at low cost. Simultaneously, an appropriate level of resources workload and minimizing of work in progress can be also important. These requirements, belonging to the different groups of criteria are often in conflict, so the only way is to develop such methods that will lead to a compromise [1],[2],[6],[11],[18]. Therefore, multicriteria optimisation theory has permanently inscribed in the scheduling issues.

Multicriteria production scheduling problems in literature are discussed widely. In [21] the thorough analysis of the scheduling optimisation, including just in time scheduling

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

robustness and some solutions to different scheduling problems are carried out. In [18] the classification problems of single- and multicriteria scheduling of the nature of the adopted model (deterministic, stochastic) production system configuration (single and multi-machine systems) is described. An example of most often-used criteria, for each configuration case, is also discussed. In [6],[11] a survey of results on multicriteria scheduling that appeared in the literature, is presented. They discussed problems of the earliness-tardiness scheduling, the scheduling with controllable processing times, simultaneous approximation, and new models.

Many interesting methods of multicriteria scheduling can be also found in computational grid systems domain. [14] describe the two-level hierarchical scheduling problem, where scheduling decisions are taken separately on grid level and next locally, in each grid. The comparison with single-criterion version of this approach was also discussed. [12] proposes an approach for scheduling a continuous stream of batch jobs on the machines of a computational grid. They develop a dispatching rule - Earliest Gap - Earliest Deadline First and tabu search method. Based on the idea of filling gaps in the existing schedule they optimize the quality of service requested by the submitted jobs and the usage of hardware.

In this paper the method of multistage process of multicriteria scheduling is described. The proposed solution is an extension of work on integrated environment for production planning and control conducted in the Institute of Automation Processes Engineering and Integrated Manufacturing Systems of Silesian University of Technology. The developed solution for small and medium-sized enterprises is dedicated as an alternative of commercial MRP/ERP (Enterprise Resource Planning) class systems and it uses results of research in both production organisation [9] and the analysis and engineering calculations (the problems of products designing stage) [24], technological processes planning (CAP/CAPP - Computer Aided Processes Planning) [4].

2. THE PROPOSED METHOD OF MULTICRITERIA OPTIMISATION

The decision-making in multicriteria production scheduling is a multi-stage process that leads to obtaining a solution as close as possible to the optimal one. According to [21] it can be considered in three general phases. The first refers to modelling of the problem. The second phase is connected with establishing the method of obtaining solution and the last, third phase refers to selecting appropriate resolution approach. In the proposed method the decision-making stages are consistent with the above and sequenced according to the scheme shown in Fig. 1.

For describing the scheduling problem the most common is symbolic notation, as the three $\alpha|\beta|\gamma$ are used [1].

where:

α – defines the resources configuration,

β – characterises assumed constraints,

γ – the objective function (optimization criteria).

Each of these sections, describing the scheduling problem on different stage is defined.

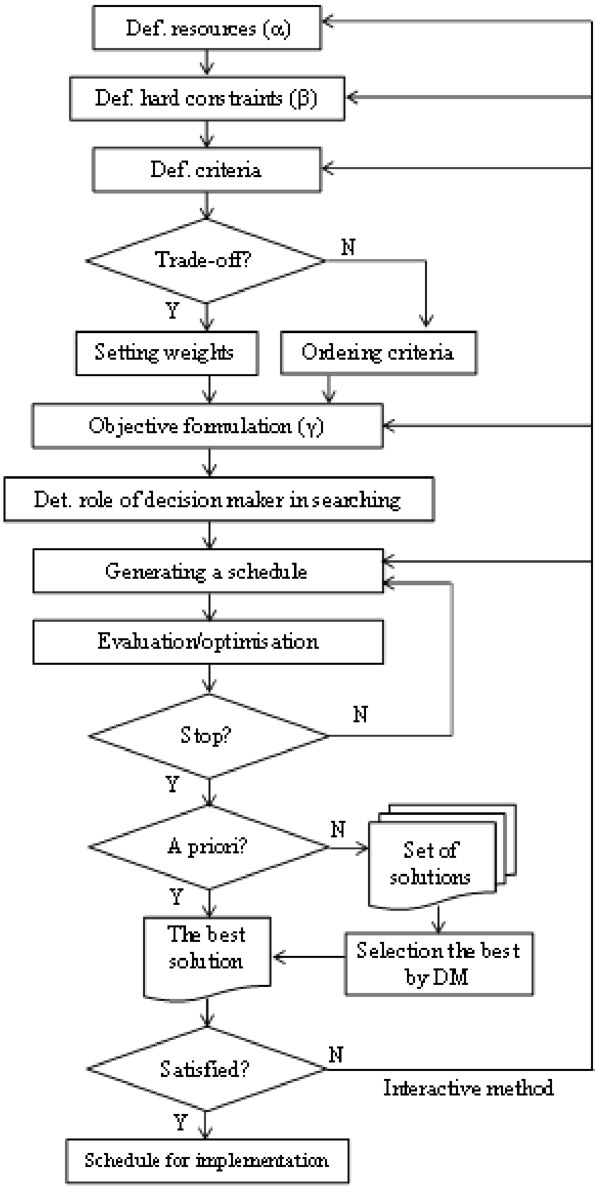

Fig. 1. The proposed procedure of multicriteria scheduling

2.1. THE SCHEDULING PROBLEM FORMULATION - RESOURCES

The decision maker formulates the scheduling problem, defines available resources like staff, machines, tools and equipment. The type of machine configuration (e.g. job shop, flow shop), skills of individual members of the staff, etc. is also important. In the production system with a stable assortment and resources configuration this step of defining the nature of the problem is performed once for many scheduling periods.

The considered model of production system consists of many different resources. The *Machine* entity represents any workplace where operations are done. Each operation is performed on a single machine. Other resources are additional restrictions for operations, are useful in planning of limited staff, tools and instrumentations. An example of a production system general structure using UML scheme is presented in Fig. 2. Each of resources uses its individual calendar. The calendar gives the timetable including free periods of a machine for assigning operations. Periods may be collected in the days and weeks, according to the applicable working time.

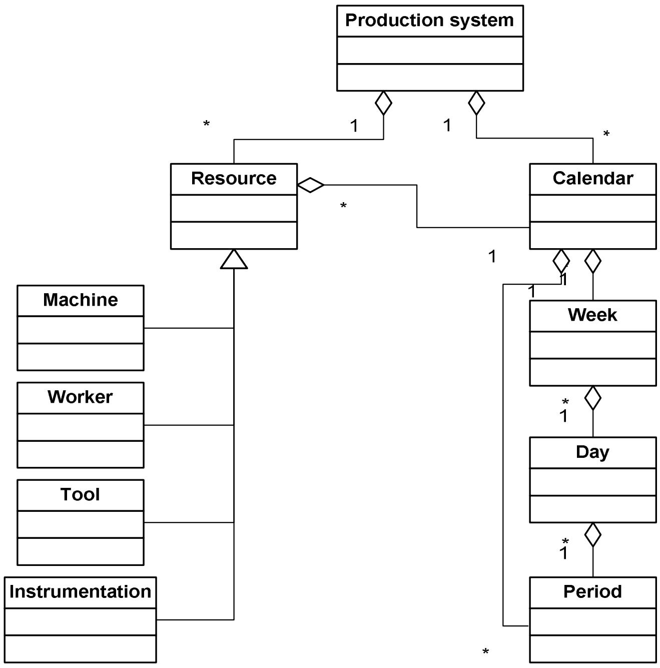

Fig. 2. The general model of production system structure

In the majority of work on production scheduling resources are limited to the set of machines and technological operations and are assigned to a single resource. In other cases, the consideration of other types of resources requires releasing of this restriction on operations, the implementation of which requires more resources (eg, machine, worker, tool). In real manufacturing system it relates to most of operations.

It was assumed, that in α section only one type of resources (e.g. machines) can be modeled and the other resources were expressed as hard constraints. In enterprises, for which an integrated system is dedicated, many types of machines configuration may occur. Due to the nature of realised production orders and the presence of the parallel machines the most suitable is the flexible job shop configuration. The possibility of identical, uniform and unrelated types of parallel machines is assumed.

2.2. THE SCHEDULING PROBLEM FORMULATION – CONSTRAINTS

When creating a production schedule, it is required to meet a number of different types of constraints. Among them, the hard and the soft constraints can be distinguished. The hard constraints must absolutely be satisfied and the soft ones, which are desirable but not necessary to be met. In tab. 1 some of the most important hard constraints were summarised. Constraints can also be given as explicit or implicit, because of other accepted constraints.

Satisfying all the hard constraints and as many as possible (a maximum number) of the soft constraints are expected from a schedule for implementation. On the other hand, there is no guarantee that for a specific set of defined hard constraints it is possible to find an acceptable (feasible) solution. In these cases, releasing some of constraints should be taken into consideration. Soft constraints can be treated as criteria and considered at the schedules evaluation stage.

Tab. 1 Summary of basic constraints considered in the model

β	Description	Possible values	Considered values
1	preemption of operations	Ø – not allowed (besides disruptions), pmtn – it is acceptable to interrupt	Ø
2	precedence constraints	Ø – operations are independent, prec – an acyclic directed graph, uan – uniconnected activity network, directed graph, operations on the edges, in-tree – an operation has at most one successor, out-tree – an operation has at most one predecessor, tree – both the in-tree and out-tree configuration is possible, chains – an operation has at most one predecessor and at most one successor, sp-graph – a set of operations described in the form of a graph series parallel.	prec, in-tree, out-tree, tree, chains, sp-graph
3	ready times of tasks (release dates)	Ø – for all tasks rj = 0, rj – times may be vary for different tasks.	Ø, r_j
4	operation times	Ø – operation times are not limited, $p_j = p$ – all operations times are equal to p, $p_{min} \leq p_j \leq p_{max}$ – operations times in a particular range $<p_{min},p_{max}>$	Ø
5	tasks deadlines	Ø – no deadlines, due dates can be defined, $\tilde{d}_j$ – deadlines are imposed	Ø
6	batching	Ø – no batching, p-batching - the entire batch processing time is equal to the longest time of the operation of the operations of the batch, s-batching - batch processing time is the sum of the operations in the batch.	Ø, p-batch, s-batch
7	Resource constraints	Ø – not defined, res – defines the required resource constraints	Ø, res,
8	Number of operations	Ø – the numer of operations is not limited, nj≤k the numer of operations is limited to k	Ø,
9	Possibility of break	Ø – breaks are possible, no-wait - without a break between operations	Ø
10	Buffers	Ø – buffers are allowed, no-store - buffers are not allowed	Ø
11	Setup times	Ø – not considered, setup – unrelated setup times, seq setup – setup times related to sequence of activities	Ø, setup,

The technological process defines a method for producing a given product, component or element. Depending on the structure of the product, a multi-level configuration of operations, where combination of machining, assembly and disassembly operations (tasks) may occur. In many cases, the technological process may include alternatives. It may be associated with parallel machines, especially not identical, used tools or instrumentation.

The production orders (job realised on the resources) are an expression of demands made by the customer in relation to the manufacturing system. The order consists of obtaining a series of homogeneous products in a limited time. It is defined by the technological process with precedence constraints, the size of the order series, release and due dates, scheduling strategy, etc. The general structure of production orders with relation to technological processes using UML scheme is shown in Fig. 3.

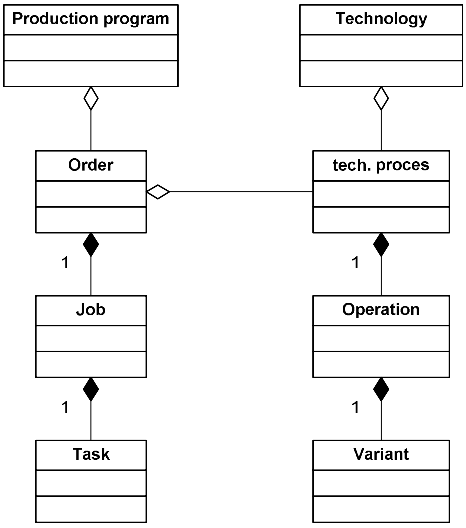

Fig. 3. The general model of production orders and technological process

2.3. THE DECISION MAKING CRITERIA

Selection of scheduling criteria depends on what the purpose of manufacturing system are placed. Evaluation criteria are related to the soft constraints defined in the system – the maximal possible value for any of them is expected, but their low value does not result in loss of solutions feasibility. The basic criteria were selected: time based and cost based. In time based connected with completion times and due dates, the following minimisations of maximal and mean performance measures were distinguished in the set of orders: C_j (completion times) F_j (flow time), L_j (lateness), D_j (absolute deviation), D^2_j (squared deviation), T_j (tardiness), E_j (earliness), U_j – (penalty unit) of order Z_j. In the set of cost criteria the setup-time costs, replacement of tools and equipment are taken into consideration.

2.4. THE OBJECTIVE FORMULATION

The method of optimisation is established at this phase. The decision maker authorises trade-offs between criteria. If trade-off is not allowed they define order in which criteria should be taken during optimisation. If trade-off is allowed, they give the weights to criteria and indicate objectives to achieve for each criterion.

Multicriteria Optimisation Theory provides methods for determining best trade-off solutions when the preferences of the decision maker are known. A general typology of multicriteria optimisation problems is presented in [21] where classification depends on information that can be provided by the decision maker. Depending on whether the trade-off between criteria is allowed, weights and goals for each criterion are defined they proposed particular class of methods for solving problems of taking into account the conflicting criteria. The approaches like convex combination, parametric analysis, Tchebycheff metrics, and goal-attainment can be found there.

Determining a utopian or ideal solution, to which a generated solution is compared, and the choice of aggregation values for each evaluation criterion have a significant impact on the development of a set of potential solutions to be used.

2.5. DEFINING THE ROLE OF THE DECISION MAKER

The decision maker can take part in the search for solutions in three different stages: before, during and after the resolution process. He also decides how scheduling system ought to give him a solution, by proposing a unique solution or more possible solutions for making the final choice. According to this, the following categories of methods can be distinguished: a priori, posteriori and interactive. In a priori methods the decision maker intervenes before searching is started and can provide a set of input information as value of the weights of criteria or an objective function. Posteriori methods give the set of solutions and the decision maker should choose the best one. It is very important to reduce the number of proposed solutions. The power of the final set should enable the decision maker to review all solutions in acceptable time. Regardless of a priori and posteriori methods, an interactive method enables the decision maker to lead the searching process iteratively [10], by setting new values of parameters, changing weights etc. in each iteration of searching process, until a satisfactory result is reached.

2.6. GENERATING SCHEDULES

The last phase is connected with the construction of an algorithm that enables obtaining a schedule for defined assumptions. Scheduling process in this paper is simplified to a single block but in real, it is composed of several stages, depending on the complexity of the model. The method should strictly comply with the hard constraints. In [8] the scheduling procedure of orders with assembly operations is presented. It describes a selection of a scheduling rule for input order sequencing, the problem of a forward and backward scheduling, decomposition of order to subprocesses and subprocesses to operations. The scheduling of operation’s alternatives is also discussed there. Scheduling of complex products is also discussed in [7], where the creation of a schedule requires five decision-making stages: orders sequencing, the choice of scheduling strategy, subprocesses and operations sequencing, selecting operation variants, schedule evaluation. The specific solutions for each stage are proposed there. An interesting solution of schedule generating and evaluation is presented in [17]. They develop a decision-support system using knowledge based system and case based reasoning.

In [18] a hybrid backwards scheduling method based on hierarchical and finite capacity shop-floor modeling and discrete event simulation is presented. For backward scheduling they propose transformation of finite capacity forwards scheduling method and both single and multiple criteria objectives. It is possible to use many different algorithms that can build a schedule according to given constraints. The idea presented in Fig. 4 is an extension of the scheduling algorithm shown in [8], where the single thread procedure for searching solutions was used. It is the conception for building a hybrid schedule-generation system by integration of the independent software: KbRS (Knowledge-based Rescheduling System [19]) and MOIA (Multi Objective Immune Algorithm) [23].

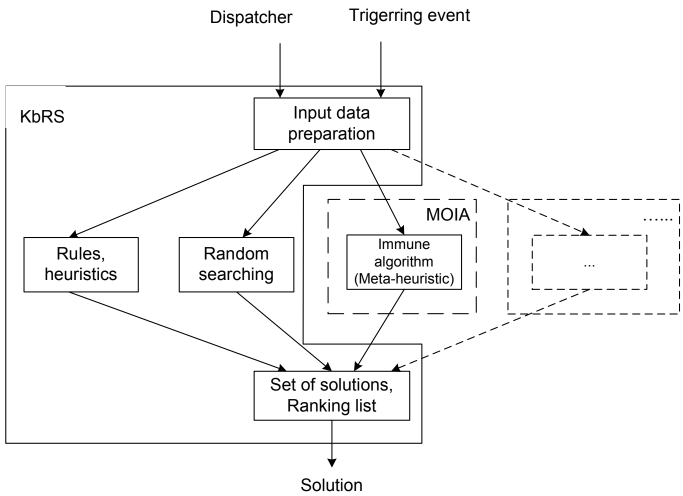

Fig. 4. Scheduling process in the hybrid schedule-generation environment

Based on current data established at the preparation stage the scheduling process is started and independent computational threads are executed. Searching for the best solution takes place simultaneously in the three modules using rules and heuristics, the immune algorithm, and a random searching. There are no obstacles to extend searching to other additional module using its own scheduling algorithm. Solutions found by different methods list are added to the common ranking.

2.7. SOLUTIONS – ACCEPTABLE SCHEDULES

In scheduling problems, where the complexity is NP-hard or strongly NP-hard there is a problem with finding the optimal solution. Therefore, at least a feasible schedule is expected. Feasibility means that all hard constraints are met in a proposed solution. If it is possible to obtain more than one feasible solution, an optimisation is needed to select the best schedule.

The problem appears when determining the final set of solutions if a posteriori method is used. Depending on the choice made by decision maker, the set of proposed solutions should include a list of solutions that have the best evaluation or set of non-dominated solutions. A solution x is dominated by another solution x’ if x’ is equally or more preferred than x for all criteria and x’ is more preferred than x for at least one criterion. In other words, there is no possibility to find another solution that is better in one criterion and simultaneously, not worse in other criteria. In the set of admissible solutions, a solution that is not dominated by any other from this set is called *effective (*optimal in Pareto sense). The subset of all effective solutions is called a Pareto set. When creating a set of solutions, different types of Pareto optimum can be distinguished: weak, strict and proper, and further non-strict, extreme weak and extreme strict. Definitions of these terms are presented in the literature on multicriteria optimisation theory, e.g. [6],[21].

If an interactive method is used then dominated solutions can become non-dominated at further stages of interaction so it is recommended to store all the solutions up to the last stage of searching the final solution. This situation does not apply to feedback to stages before objective formulation, where solutions may lose admissibility.

Searching for optimal solutions in the Pareto sense, in extreme cases, can lead to solutions where the minimum is reached only for one criterion and for the other, it is very far from the optimal (e.g. the case in which one has everything and all the others – nothing). Therefore, in practice, it is also worth considering to find the optimal solution in the sense of Kaldor–Hicks [20]. This efficiency is an extension and generalization of Pareto efficiency.

3. REQUIREMENTS OF PRODUCTION SCHEDULING SYSTEM

The proper cooperation of a scheduling system in the integrated manufacturing environment needs to be settled on at the many different levels. The complete specification should include a detailed description like in [16], where requirements of the scheduling system are classified into following groups: general, resources, constraints, activities, scheduling and rescheduling capability, output, user interface and control, and system interface requirements. The most important of them, taking into account current stage of this research are presented below. They apply to detailed scheduling model (resources, technological processes, production orders) and as well as precise behaviour of the system. The requirements of behaviour concern an online operation in a changing environment, a limited and guaranteed time for creating a solution and interactivity. This allows the scheduling system to be considered as a real-time system (RTS).

3.1. SCHEDULING AS REAL TIME SYSTEM

The method of treatment of a dynamically changing manufacturing system state is one of the basic problems of production scheduling. Some unexpected events like resources failures, new or cancelled orders, changed ready times or due dates, etc., may have influence on the system performance and cannot be omitted. In these cases, a current, realised schedule should be updated. From the scheduling system it is required to react quickly to changes, which impose an adequate method of delivering solutions. Requirements for response times depend on the implementation, and may range from milliseconds to the minutes, hours, days or longer periods and can vary even within the same application. Therefore, it is important to include, with a description of the event, the information about the required response time. A longer period of time usually allows to find a better solution. Besides rescheduling there are other approaches like dynamic or robust scheduling. A review and classification of solutions in those systems are thoroughly presented in [22].

Scheduling in dynamic systems is based on the registered state of the environment, so two differing states are distinguished: an internal and external state. The internal state is entered into the scheduling system as the basis for searching solution. The external state means the state of the real production environment. It is important that at the time of the searching solution the external state has not be changed significantly, which can cause a solution to be outdated.

Depending on the requirements of the scheduling system's response time (deadline, t_{dead}) the following kinds of real time systems are distinguished: hard, firm and soft. Fig. 5 shows the usefulness of the solution in relation to the elapsed time.

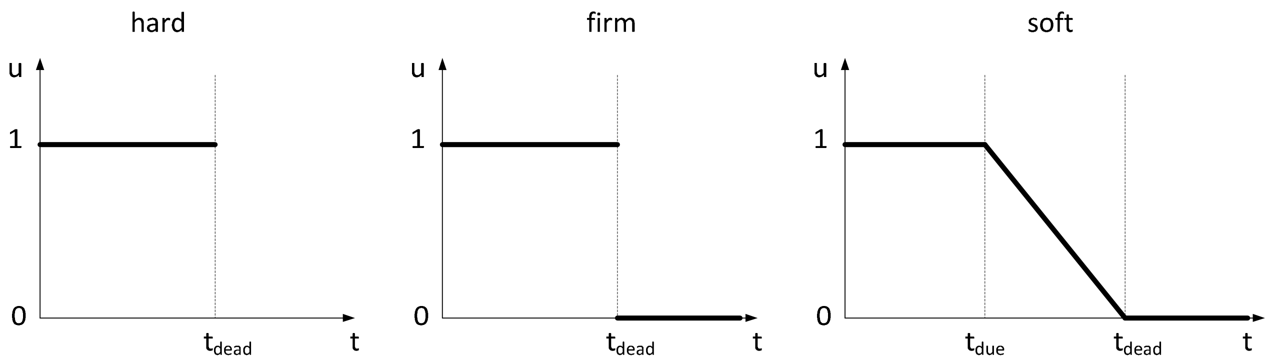

Fig. 5. The usefulness of the solution in hard, firm and soft RTS

In hard and firm RTS the worst (longest) response time is known, and it is also assumed that it will not be exceeded. In hard RTS overrunning a deadline causes very serious consequences, in firm RTS this situation will only bring uselessness of the result. Soft RTS try to respond as soon as possible, but we do not know, what may be the worst response time. In this case, both the due date (t_{due}) and deadline can be distinguished. After the due date, the solution becomes less and less useful, up to the deadline, which causes complete usefulness. It is required that scheduling system should work in soft RTS conditions. In the response time of the system the time required to collect and provide the necessary input data must also be taken into account. This is especially important when rescheduling, where the information about the event and its impact on the production system (resources, orders) is required. Another important thing is to determine the interactivity of the scheduling system. The participation of the decision maker in the process of scheduling should be closely specified. Depending on the needs, the dispatcher should be able to intervene in the process of creating a solution and make a final decision on his selection.

4. THE INTEGRATED ENVIRONMENT OF PRODUCTION PLANNING AND CONTROL

The developed production planning and control environment integrates three independent software systems: Proedims - the PDM class system, KbRS - the Knowledge based Rescheduling System and SWZ - the system of order verification [13]. This environment in cooperation of Silesian and Wroclaw University of Technology was elaborated. The presented method is related to the cooperation of the system Proedims and KbRS in the scheduling area. The basic data flow between systems is shown in Fig. 6.

The Proedims that belongs to a class of systems, is used to manage product data and processes in the enterprises (PDM) and it is the fundamental part of the integrated environment. It enables the creation, storage, management, and propagation of all the data related to the product throughout its life cycle. It supports different areas and activities associated with the product and company activities, from the conceptual phase of product development, through project management, logistics processes and relationships with customers and suppliers, to the maintenance and servicing of products. The SWZ and KbRS systems extend the functionality of Proedims for specialized calculations. The scheduling and rescheduling system KbRS is a solution dedicated for multiassortment production systems. Using event driven rescheduling approach, the system can be used for a creation and updating schedules. According to a given specific indicators system can search for a solution and propose a set of the highest rated schedules for implementation to a decision maker. The Proedims was implemented in several mechanical manufacturing enterprises. As a part of development work, there was a need to extend the functionality of balancing production capacity and detailed production scheduling. Therefore, it was decided to join Proedims with SWZ and KbRS. Testing in a pilot case of the integrated environment was a part of the project N R03 0073 06/2009 – “Integrated, management system for variable and multiassortment production to order in small and medium-sized enterprises” supported by The Polish National Centre for Research and Development.

In the case of scheduling and rescheduling, the basis of efficient planning and reaction to registered disturbances or variations in production is a quick access to technological and organizational data on production orders – variants of processes, deadlines, priorities, and the volume of production. This information is usually stored in databases of MES, ERP, PDM or/and CAPP class systems. The analysis made in the first stage of the integration has shown that in the considered instance it is enough to develop a dedicated data exchange protocol between systems, instead of establishing direct access to particular databases. The main reasons indicate greater flexibility of this approach, allowing a further independent development of the individual subsystems. The elaborated communication method based on extensible markup language XML using XML schema and XSLT was established and presented in [19].

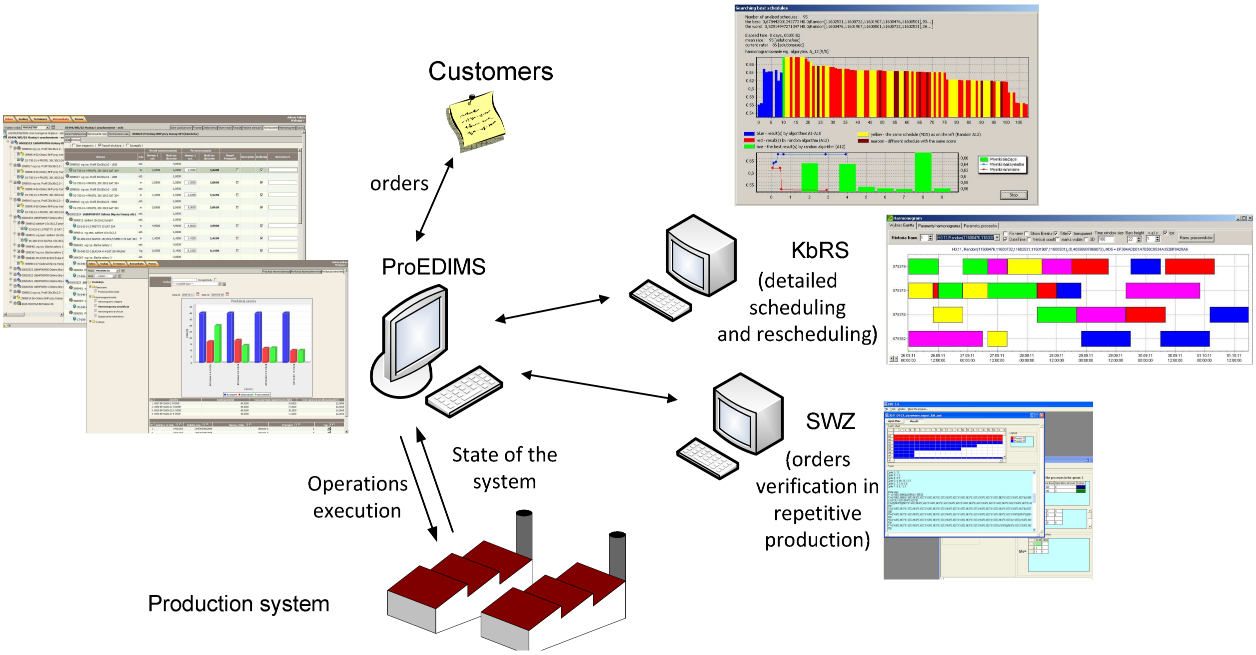

Fig. 6. Information exchange in the integrated Proedims, KbRS and SWZ environment

The analysis of the first preproduction implementation results indicates the need to develop the multicriteria scheduling and rescheduling method for enabling more behaviour scenarios to the decision maker concerning to real time operating conditions. The basic requirements of considered production systems in relation to scheduling system and the elaborated method in the next sections are presented.

5. SUMMARY

The paper indicates that decision-making problem affects many phases of multicriteria production scheduling. The overall treatment of the subject has been attempted and the distinguished steps include both the preparation and the implementation phase of production scheduling.

Despite the possibilities of use one of three different ways of the user participation in the process of finding the best solution, the priori method is not applied in practice. External, human control over the process of scheduling can include additional criteria, not considered in the system is still the most popular, so decision maker prefers posteriori or interactive method. However, this does not change the fact that different scenarios allow applying an individual approach separately to every decision situation, both in scheduling and rescheduling.

The developed method is the basis for the next stage of integration of Proedims and KbRS systems, being implemented in small and medium-sized enterprises of mechanical industry. These companies, working in a make-to-order (MTO) scheme, usually realize orders for the needs of large companies or corporations. The proposed solutions may improve the efficiency of the production planning and scheduling stages by enabling faster and more accurate determination of the system of performance indicators, and thus a better use of available capacity. The proposed solution can be applied also in other industries characterized by discrete manufacturing, which requires adjustment of a model of resources, constraints and the objective function. The successful implementation largely depends on the solutions, which allow the operation of the scheduling system in real time conditions.

The application of the presented methodology in an integrated environment is not the last step in the development of the system. The operation with incomplete and limited information is foreseen for further research.

REFERENCES

[1] BŁAŻEWICZ J., ECKER K.H., PESCH E., SCHMIDT G., WĘGLARZ J., 2007*Handbook on Scheduling. From Theory to Applications,* Series: International Handbooks on Information Systems, Springer-Verlag Berlin Heidelberg,.

[2] CHRYSSOLOURIS G., 2005, *Manufacturing Systems: Theory and Practice,* Mechanical Engineering Series, Springer.

[3] FRAMINAN M.J., RUIZ R., 2010, *Architecture of manufacturing scheduling systems*: *Literature review and an integrated proposal*, European Journal of Operational Research, 205/2, 237–246.

[4] GRABOWIK C., KALINOWSKI K., 2011, *Object–Oriented Models in an Integration of CAD/CAPP/CAP Systems*, Lectures Notes in Artificial Intelligence, LNAI 6678, Springer, II, 405–412.

[5] GRABOWIK C., KRENCZYK D., KALINOWSKI K., 2012, *The Hybrid Method of Knowledge Representation in a CAPP Knowledge Based System*, HYBRID ARTIFICIAL INTELLIGENT SYSTEMS, PT II Book Series: Lecture Notes in Computer Science,7209, 284-295.

[6] HOOGEVEEN H., 2005, *Multicriteria scheduling*, European Journal of Operational Research, 167, 592–623.

[7] KALINOWSKI K., 2011, *Decision making stages in production scheduling of complex products*, Journal of Machine Engineering, 11/1-2, 68-77.

[8] KALINOWSKI K., 2009, *Scheduling of production orders with assembly operations and alternatives*, Flexible Automation and Intelligent Manufacturing, Proc. Int. Conf. FAIM 2009, University of Teesside, Middlesbrough, UK, 85.

[9] KALINOWSKI K., SKOŁUD B., GRABOWIK C., KRENCZYK D., 2007, *Computer aided technological and organizational processes planning,* Proceedings of the Contributions of 15th International Scientific Conference, CO-MAT-TECH 2007, Quality Assurance Of Products, Safety Of Production And Environment, 18 – 19, October 2007, TRNAVA, 173-176.

[10] KALISZEWSKI I., 2006, *Soft Computing for Complex Multiple Criteria Decision Making*, International Series in Operations Research & Management Science, 85, Springer.

[11] KEMPF K., UZSOY R., SMITH S., GARY K., 2000, *Evaluation and comparison of production schedules*, Computers in Industry, 42, 203–220.

[12] KLUSÁČEK D., RUDOVÁ H., BARAGLIA R., PASQUALI M., CAPANNINI G., 2008, *Comparison Of Multi-Criteria Scheduling Techniques*, Grid Computing, 173-184.

[13] KRENCZYK D., KALINOWSKI K., GRABOWIK C., 2012, *Integration Production Planning and Scheduling Systems for Determination of Transitional Phases in Repetitive Production*, HYBRID ARTIFICIAL INTELLIGENT SYSTEMS, PT II Book Series: Lecture Notes in Computer Science, 7209, 274-283.

[14] KUROWSKI K., NABRZYSKI J., OLEKSIAK A., WEGLARZ J., 2008, *Multicriteria approach to two-level hierarchy scheduling in grids*, Journal of Scheduling archive, 11/5, October 2008, 371 – 379.

[15] LALAS C., MOURTZIS D., PAPAKOSTAS N., CHRYSSOLOURIS G., 2006, *A Simulation-Based Hybrid Backwards Scheduling Framework for Manufacturing Systems*, International Journal of Computer Integrated Manufacturing, 19/8, 762-774.

[16] LIEBOWITZ J., POTTER W. E., 1995, *Scheduling Objectives, Requirements, Resources, Constraints, and Processes: Implications for a Generic Expert Scheduling System Architecture and Toolkit*, Expert Systems with Applications, 9/3, 423-432.

[17] MIKULAKOVA E., KÖNIG M., TAUSCHER E., BEUCKE K., 2010, *Knowledge-based schedule generation and evaluation*, Advanced Engineering Informatics, 24, 389–403.

[18] NAGAR A., HADDOCK J., HERAGU S., 1995, *Multiple and Bicriteria Scheduling: A Literature Survey*, European Journal of Operational Research, 81, 88-104.

[19] SKOŁUD B., KRENCZYK D., KALINOWSKI K., GRABOWIK C., 2010, *Exchange of data in production flow control systems SWZ and KBRS*, Automatyzacja Procesów Dyskretnych. Teoria i Zastosowania (Świerniak A., Krystek J.), Gliwice, 207-214, (in Polish).

[20] STRINGHAM, E. P., 2001, *Kaldor-Hicks Efficiency and the Problem of Central Planning*, Quarterly Journal of Austrian Economics, 4/2, 41-50.

[21] T'KINDT V., BILLAUT J.C., 2006, *Multicriteria Scheduling: Theory, Models and Algorithms*, Second Edition, Springer Berlin Heidelberg, New York.

[22] VIEIRA G. E., HERRMANN J.W., LIN E., 2003, *Rescheduling Manufacturing Systems: a Framework of Strategies, Policies, and Methods*, Journal of Scheduling, 6, 39-62.

[23] WOSIK I., SKOŁUD B., 2009, *Tuning of a fuzzy system for controlling searching process in multi objective scheduling immune algorithm*, Journal of Machine Engineering ,9, 130-143.

[24] ZOLKIEWSKI S., 2010, *Numerical Application for Dynamical Analysis of Rod and Beam Systems in Transportation*, Solid State Phenomena, Trans Tech Publications, 164, 343-348.