Monostori, L.; Váncza, J.; Márkus, A.; Kádár, B.; Viharos, Zs.J.; Digital Enterprises: First results of a national R&D project, *2003 IEEE/RSJ International Conference of Intelligent Robots and Systems, IROS 2003*, October 27-31, 2003, Las Vegas, Nevada, U.S.A., IEEE, ISBN: 0-7803-7861-X, pp. 2335-2340.

Digital Enterprises: First results of a national R&D project

László Monostori, József Váncza, András Márkus, Botond Kádár, Zsolt J. Viharos
Computer and Automation Research Institute, Hungarian Academy of Sciences
Kende u. 13-17, H-1111, Budapest, Hungary, Phone: (36 1) 297-6159, Fax: (36 1) 4667-503,
e-mail: {laszlo.monostori, vancza, markus, kadar, viharos}@sztaki.hu

Abstract - Today's complex manufacturing systems operate in a changing environment rife with uncertainty. The performance of manufacturing companies ultimately hinges on their ability to rapidly adapt production to current internal and external circumstances. Partly based on a running national research project on digital enterprises and production networks, the paper illustrates how the concepts of intelligent manufacturing systems and digital enterprises can contribute to the solution of the above problems.

I. INTRODUCTION

Manufacturing systems of these years work in a fast *changing environment* full of *uncertainties*. Increasing *complexity* is another characteristics which shows up in production processes and systems and in enterprise structures as well [1], [2]. One of the recent areas of research is related to the *globalization* of production. *Production networks* (PNs) are formed from independent companies collaborating by shared information, skills, resources, driven by the common goal of exploiting market opportunities [3].

The concept of the *digital enterprise*, i.e. the mapping of the key processes of an enterprise to digital structures by means of information and communication technologies (ICT) gives a unique way of managing the above problems. By using recent advances of ICT, theoretically, all the important production-related information are available and manageable in a controlled, user-dependent way [4].

However, the management, the optimal or near to optimal exploitation of this huge amount of information cannot be imagined without the effective application of the methods and tools of *artificial intelligence* (AI), sometimes, more specifically, *machine learning* (ML) techniques [5].

The development and application of intelligent decision support systems will help enterprises to cope with the problems of uncertainty and complexity, to increase their efficiency, to join in production networks and to improve the scope and quality of their customer relationship management [4].

According to [6], *digital enterprise technology* (DET) can be defined as "the collection of systems and methods for the digital modeling of the global product development and realization process in the context of lifecycle management". In the same paper, five main technical areas are outlined as cornerstones for realizing digital enterprises:

- distributed and collaborative design,
- process modeling and process planning,
- production equipment and factory modeling,
- digital to physical environment integrators,
- enterprise integration technologies.

The fundamental aim of the paper is to introduce our attempts towards the realization of digital enterprises. Particular parts of our approach have been conceived and developed in the framework of a project run in Hungary on Digital Enterprises, Production Networks [4], [26] supported by the National Research and Development Program (NRDP). The partners in the project build a well balanced "academia-industry" cluster: a multinational manufacturing enterprise, an SME working in ICT are on the industrial side, while academia is represented by the Budapest University of Technology and Economics, the Miskolc University, and the Computer and Automation Research Institute, Hungarian Academy of Sciences (SZTAKI).

Following the above cornerstones of the digital enterprise technology, the paper introduces some novel research results achieved at SZTAKI, partly in cooperation within the national project, as possible contributions to the realization of digital enterprises.

II. COLLABORATIVE DESIGN AND CONCURRENT ENGINEERING

A. Project-based planning

Our approach is applicable primarily in industries where complex, resource and cost intensive one-of-a-kind products are made on an *engineering-to-order* basis. Further on, we consider production in a *network* where decisions on the allocation of tasks and the use of resources should concern both *internal* and *external* capacities; where the internal flow of materials should be synchronized with the incoming and outgoing flows [3]. All this makes the problem of planning extremely hard to solve. Conversely, the complex situations call for efficient, robust decision support methods. Hence, there is a need for intuitive and flexible models *and* fast, reliable solution techniques that scale-up well also to large problem instances.

To handle this complexity we apply the principle of *aggregation* and remove certain details in the representation of products and orders, production processes, resource capacities, as well as of time. For instance, the time horizon is long and medium term, with a week's time unit. However, contrary to traditional approaches, we do not apply decomposition to split the problem into a load and a capacity-oriented sub-problem.

The basic idea is to model orders as *projects* that compete for a number of limited-capacity *resources*. Our method is based on a generalized version of the *resource-constrained project scheduling* problem [8] and unifies the resource and the material flow oriented aspects of production and capacity planning. Resource-constrained project scheduling problems are concerned with scheduling a number of discrete activities, each requiring some resources. Constraints due to the limited capacities of resources and precedence relations between the activities are prescribed. The classical model assumes fixed activity durations and a constant rate of resource usage during the entire processing of every activity. However, in *aggregate* planning the above assumptions cannot be taken and there is either no need to generate detailed solutions for future periods that will certainly be different from what is anticipated. Hence, we extended the classical model so that

- each activity can be executed with varying (even zero) intensity, and
- resources can be shared out among activities continuously.

B. Resource-constrained project scheduling

Projects may include various *activities* that are needed to complete an order; e.g., engineering design, technological process planning, components manufacturing, assembly, programming, documentation, installation, deployment. Although some logical ordering of the activities is to be followed, many of them may overlap in time, especially in case of large projects. Each activity may call for the use of a number of different resources. The required resources are typically both machines and human work force that should be shared by the activities of the different projects. The resources may be distributed, geographically dispersed and belong even to different organizations.

Each product order is considered as a project. Projects have *time windows* given by their earliest start and latest finish date. A project consists of activities that are linked by *precedence* constraints. Each *activity* may require several resources and the execution of a given *amount of work*. However, the *intensity* of executing an activity may vary over time; the activity can even be pre-empted. Activities here are *aggregates*: they represent a logical group of design, manufacturing, assembly, etc. operations, some of which are executed simultaneously, others sequentially, and still others independently of each other. This leads to a model in which neither the processing times of activities are fixed, nor their intensity is constant over time. However, the amount of work needed to process them is fixed. The solution of a problem instance is a project schedule which specifies what portions of which activities have to be done in each time unit, so that all the precedence and capacity constraints be respected, and the schedule is optimal in the sense of the use of external resource capacities. (For further details, see [9].)

Having introduced variable-intensity tasks and continuous resources, the model can be solved by customized mathematical programming methods very efficiently. Hence, it can be applied in a dynamic setting when re-planning is initiated by unexpected changes.

C. Industrial application

The method was applied in a factory that produces complex, one-of-a-kind equipment. The *internal* resources were well-organized and stable. At subcontracting partners, there have been *external* capacities for all resources, but for a given, higher unit costs. Orders were modeled as independent projects. The problem is to determine the timing and resource assignments of the activities of all the projects so as to satisfy the temporal and resource constraints, and to minimize the cost of external resource usage. Production and capacity planning should be supported in an integrated way, at two levels of aggregation [10]:

- On the long term, with a 1-1.5 year horizon, by considering the various departments (such as mechanical design, components machining, mechanical assembly, electric design, electric assembly, installation, etc.) as resources.
- On the medium term, with a quarter horizon, by considering the groups of machine and labor resources of components machining.

Tests were run with the following typical settings: on a higher aggregation level 5 to 10 resources had to be dealt with and were required by some 150-250 activities. Problems on a lower level were of the same complexity since they had more resources, but due to the shorter planning horizon, fewer activities. Worst case problem instances were optimally solved on a 1.6 GHz personal computer within 90 sec. Typical solution time for real-life instances was less than 30 sec. Hence, thanks to its efficiency, the solver is applicable as the engine of an interactive, decision support production planner system. As an illustration, see Figure 1.

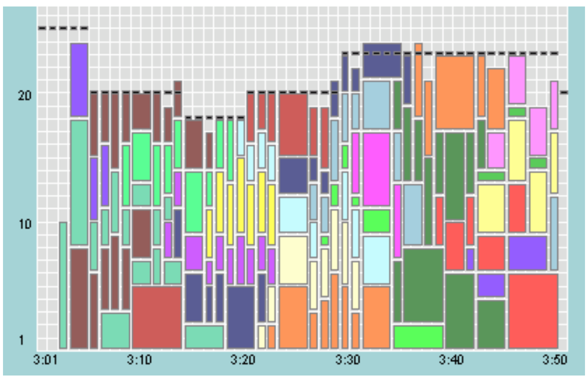

Figure 1: Load of the “mechanical design” resource, with external needs above the internal capacity limit (dotted line).

The method is able to support planning even if no detailed information on product and production technology is available. Hence, it can be applied to planning the future load of a factory, to determine external capacity requirements right before the detailed design of a product is started. Naturally, as design proceeds, and more information is available on the products, the project model can be refined and solutions can be re-generated.

III. PROCESS MODELING AND PROCESS PLANNING

Manufacturing process planning connects the worlds of design and production. *Computer-aided process planning* (CAPP) holds the promises of better designs, lower production costs, larger flexibility, and improved quality. The CAPP problem is extremely complex because it has to include aspects of both design and production: it has to cover geometry and tolerances, material properties, manufacturing processes and tools, fixturing and holding devices, machines and other equipment used in production. CAPP is an *ill-structured problem* because it is hard to find an appropriate fit between the particular planning problem, the available domain knowledge, its representation, as well as its utilization. Consequently, planning expertise is typically a collection of fragmentary, context-dependent, often conflicting pieces of advice.

Attempts to give structure to CAPP problems have to rely basically on *symbolic representation* and *reasoning* methods. To support low-level planning - i.e., to determine the parameters of machining operations - *subsymbolic* methods seem to be more suitable. In what follows we give a short account of our research in both fields.

A. Constraint-based CAPP

In solving CAPP (as any other complex engineering) problems, the main methods are *reasoning* and *search*. However, in real-life cases reasoning has to face ambiguity and incompleteness, whereas search has to cope with complexity. The crux of all but the simplest CAPP problems is just to reconcile the logical and optimization aspects of planning and to handle inconsistent pieces of technological knowledge.

Hence, we suggested a model for CAPP that can capture as many domain knowledge as possible in a declarative way. However, the model should not be either complete or consistent [11], [12]. The model is based on *constraints* that specify properties of process plans. Constraints have some features that make them particularly suitable for modeling partial plans: they are declarative, non-directional, additive, mutually dependent and can also express partial information. Hence they state clearly what has to be satisfied without binding in any way how. Constraints are suitable for maintaining distributed, locally incomplete representations of plans.

The model captures pre-defined resource, precedence and grouping (so-called setup) constraints, and provides means for representing conditional as well as hard and soft constraints. Hence, *inconsistent* bodies of domain knowledge can also be handled. An actual instance of the CAPP problem is built up by CAD and CAM related information (see Figure 2).

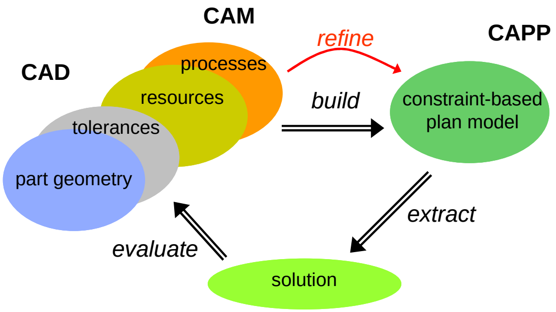

Figure 2: The problem solving cycle in CAPP.

Actual solutions – partial and complete process plans – are extracted from the constraint based model by using the techniques of *constraint programming* (CP) that combine techniques of constraint satisfaction, branch-and-bound search and heuristic optimization. However, so as to handle soft constraints, the standard CP methods had to be extended with search techniques that find – and in a way maximize – consistent bodies of domain knowledge.

Partial and final solutions generated during the problem solving process are passed back for evaluation. If the evaluation renders a plan infeasible, it should also refine the model so as to exclude the generation of wrong plans in the subsequent steps of the planning process.

B. CAPP-CAD integration in sheet metal bending

Recently, we have applied the above constraint-based CAPP model in a real-life engineering domain, the bending of sheet metal parts [13]. In this domain where geometry plays a key role, traditional engineering knowledge consists of fragmentary, sometimes contradictory pieces of advice and the solutions are evaluated according to multiple criteria. It is hopeless to capture all domain knowledge a priori, before planning time. Hence, after starting with an initial model, partial solutions are evaluated and some planning constraints are generated on the fly.

The solution process is based on the communication of a general-purpose constraint solver and a domain-specific geometric expert. The geometric module works on an exact spatial representation of the part, machine and tools and generates and successively refines constraints that the solutions must satisfy. The other module solves the dynamically evolving constraint models by combining techniques of constraint propagation, branch-and-bound search and multi-criteria optimization. For an overview of the system, see Figure 3.

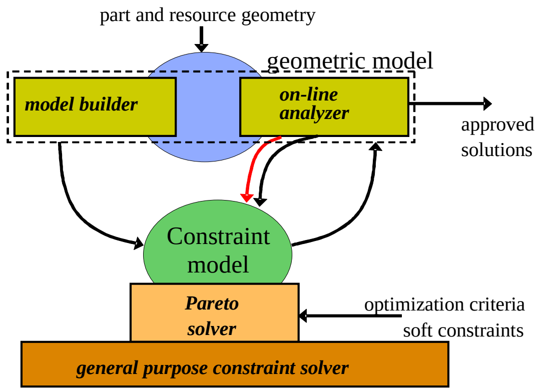

Figure 3: The communication structure of the CAPP-CAD planner.

C. Capturing process knowledge by subsymbolic methods

Difficulties in modeling manufacturing processes are manifold: the great number of different machining operations, multidimensional, nonlinear, stochastic nature of machining, partially understood relations between parameters, lack of reliable data, etc. A number of reasons back the required models: the design, optimization, control and simulation of processes and the design of equipment.

Artificial neural networks (ANNs) proved to be applicable for monitoring production processes [14]. In [15] a novel approach was described for generating multipurpose models of machining operations, combining machine learning and search techniques. A block-oriented framework for modeling and optimization of process chains was also introduced.

In one of our recent works the main issue is to automatically identify parts of a large system (e.g. a complex process chain) which can be modeled independently. It can be regarded as the inverse of the previous approach, i.e. instead of building up a large model on the base of sub-models; the goal of research is to automatically determine individual parts of a complex system, which can be modeled separately.

By this way, on the one hand, a deeper insight into the processes can be achieved, and on the other hand, more easily treatable sub-models and their connections can be automatically generated [16]. The approach is based on searching for appropriate, artificial neural network based sub-models where the input-output mapping can be relatively easily accomplished by neural learning.

IV. ADVANCED FACTORY EQUIPMENT AND LAYOUT DESIGN AND MODELING

Simulation techniques can be advantageously used in the design of new production plants. In [15], in addition to the modeling and optimization of manufacturing processes and process chains, the concept of a hybrid, AI-, ML- and simulation-supported optimization of production plants was also outlined.

According to this concept, the production plant is represented as a chain of processes where the most important parts are simulated by appropriate (in most cases discrete event) simulation packages. In the case of plant optimization, most of the parameters are fixed and - satisfying some constraints - the values of other parameters are to be determined in order to reach some performance measures. Naturally, some constraints have to be satisfied, as well.

It is appropriate to replace the time consuming simulation with ANN-based models initially trained by patterns generated by the plant or - in most cases - by its simulation. The optimization framework described in [15], can search for solutions by using the ANN models. Whether a found solution is appropriate, i.e., it is within the region appropriately realized by the ANN model(s), is to be checked by simulation. If this run indicates unexplored region, the related patterns are added to the training sets of the ANNs and after training, a new optimization step is started. If the simulation provides with reinforcement, the solutions are further used for the determination of the system parameters searched for.

Some results of an industrial project demonstrated the applicability of the concept. The actual task was to optimize the size spectrum of the ordered raw material at a plant producing one- and multi-layered printed wires [15].

V. PHYSICAL TO DIGITAL ENVIRONMENT INTEGRATORS

The physical to digital environment integrators represent a wide range of technologies that can be used for the bi-directional transfer and communication of data, models, measurements as well as process status and expert feedback between the digital and the physical domains [6]. In this section, three attempts are described in this direction.

A. Simulation-supported production-scheduling

We are developing an integrated production planner and job shop scheduler system with flexible modeling capabilities and powerful, scalable solution methods. The system generates close-to-optimal production and capacity plans on the medium term, and detailed production schedules on the short term. Production plans and schedules, let they be generated by the most sophisticated methods make not much sense if they cannot be executed. However, assumptions (e.g., concerning resource availability, production technology) taken by planning time are often violated at execution time. The closer we are to the realization of plans and schedules, the higher is the chance of unexpected events that can render plans and schedules inadequate. That is why practical scheduling is driven by uncertainty, and the methods applied in dynamic job shops rarely utilize theoretical results [17].

However, the deterministic constraint-based factory model can hardly account for all the *uncertain events*, especially for those that may happen on the shop floor. Hence, we include such factors into our simulation model, which will be used to evaluate the results of the constraint-based scheduler in face of uncertainties. Uncertainties modeled within the simulation model relate (1) delivery and (2) quality of incoming material; (3) machine downtimes, (4) processing times and (5) insertion of extra, adjustment operations into the routings [18]. In this setting, simulation will capture the relevant aspects of the production planning and scheduling problem which cannot be represented in a deterministic, constraint-based optimization model. It will offer a benchmark platform for the generated (close-to) optimal schedules, help to evaluate the robustness of daily schedules against the above uncertainties and to support the systematic test of the production planning and scheduling system.

B. Agent-based control of traditional manufacturing systems by using simulation

In this section a novel approach to the holonification of whole manufacturing systems is outlined, based on an extension of the *Virtual Manufacturing* (*VM*) concept [19]. Manufacturing sub-systems can be classified into four categories: Real Physical System (RPS), Real Informational System (RIS), Virtual Physical System (VPS), Virtual Informational System (VIS).

A fundamental feature of the VM concept is that it realizes a one-to-one mapping between the real and virtual systems, i.e. VIS and VPS try to simulate RIS and RPS, respectively, as exactly as possible. In [20] an extension of VM concept was suggested and illustrated. The main novelty of the approach is the break with the above one-to-one mapping, more exactly the use of the VM concept to control a traditional (centralized / hierarchical) manufacturing system in a holonic [20] way.

The virtual part of the system runs in a holonic way and incorporates order management, scheduling and control issues. Resource agents which, from the technological point of view, correspond to the real resources of the traditional system can be easily constructed by using the object library of the simulation framework [21]. Order management proceeds fully in the virtual system.

Decisions are made in the virtual, holonic system and conveyed to the VIS of the traditional system. The real production situation is sensed by the RPS and forwarded to the VIS, which initiates appropriate measures in a holonic way. As a summary, the traditional system shows a holonic behavior.

The holonic information system tested in a virtual environment has the potential of being used in real holonic systems.

As a further development of the above approach, in one of our running projects, the described general concept is used for production scheduling, based on adaptive agents [22]. More exactly, high-level algorithms, including machine learning, neurodynamic programming run on the virtual level, taking the advantage of the significant speed difference which characterizes the virtual and real systems.

C. Advanced monitoring of complex production structures

Based on the successful results of applying ANNs for monitoring manufacturing processes [14], two hybrid AI solutions for supervision and control of manufacturing processes with different degrees of integration were introduced later.

One of the main goals of the national research project on digital factories and production networks as referred to in the introduction is to develop algorithms suitable for monitoring complex production structures [4].

Advanced monitoring systems based on multisensor information, machine learning, data mining, etc., should support the measuring and processing of a large amount of data (e.g. 5-10000 samples per second) and give appropriate information for:

- the control level to initiate necessary intervention into the production in order to prevent additional losses and damage,
- personnel to make necessary further measures, maintenance activities,
- the management level about the operation of the production system.

Naturally, the high number of measurements of monitoring parameters causes a certain amount of incomplete data, so their appropriate handling constitutes another important subject of the project.

In order to accelerate the development and to enlighten the practical application of monitoring systems, appropriate, monitoring–related simulation of the production plants is also envisaged [16].

VI. ENTERPRISE INTEGRATION TECHNOLOGIES

The objective of the project to be presented here is to conceive and develop a framework based on autonomous, cooperative agents for production management in production networks [24].

The *Production Network Management System (PNMS)* proposed here supports the functioning of several companies, considered as agents, working together for fulfilling a job-order (request) from an external customer. The companies, seen as agents, may be product or service providers. In the PNMS, there are no pre-set relationships between agents.

Special emphasis is given on the elaboration of an availability (capacity analysis) and detailed scheduling model for companies involved in the PN, by using constraint programming techniques.

The PNMS to be presented here represents an attempt to open production planning from an internal, intra-enterprise activity, onto Internet / Extranet.

When a job-order is received, negotiation processes [25] emerge in the production network. The components of the system may change according to the external situation even after the order has been accepted. Naturally, the agents are self-interested and, within certain constraints, free to join, remain in or leave the network.

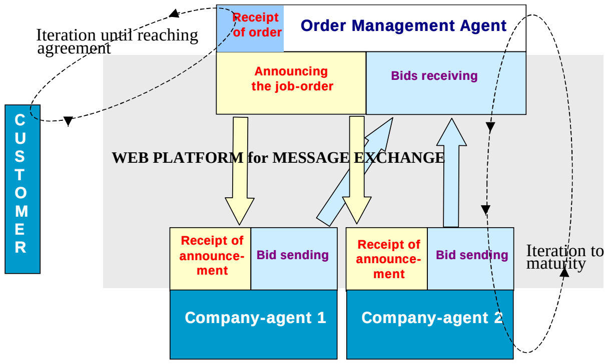

Figure 4: The information exchange of the developed web platform

The information exchange will enter an iteration process until reaching a satisfactory solution (each task of the work order accomplished under the terms agreed with the customer) (Figure 4) or will be stopped if no solution is found.

VII. CONCLUSIONS

Attempts towards the realization of digital enterprises were outlined in the paper, according to the five cornerstones of digital enterprise technologies given in [6]. As the described approaches illustrate, the realization of digital enterprises requires latest information and communication technologies and AI and ML methods. However, in order to fully exploit the potential benefits of digital enterprises and production networks, further research and development activities are needed, also in the framework of international cooperation.

VIII. ACKNOWLEDGMENTS

The research was supported partially by the project "Digital enterprises, production networks" in the frame of the National Research and Development Program by the Ministry of Education (Grant No. 2/040/2001). A part of the work was covered by the National Research Foundation, Hungary, Grant Nos. T034632 and T043547.

IX. REFERENCES

[1] H.-P. Wiendahl, P. Scholtissek, "Management and control of complexity in manufacturing", *CIRP Annals*, vol. 43, no. 2, 1994, pp. 533-540.

[2] K. Ueda, A. Márkus, L. Monostori, H.J.J. Kals, T. Arai, "Emergent synthesis methodologies for manufacturing", *CIRP Annals*, vol. 50, no. 2, 2001, pp. 535-551.

[3] H.-P. Wiendahl, S. Lutz, "Production in Networks", *CIRP Annals*, vol. 51, no. 2, 2002, pp. 1-14.

[4] L. Monostori, G. Haidegger, J. Váncza, Zs.J. Viharos, "Digital Enterprises: A national R&D project in Hungary", in *Proceedings of the 1st CIRP (UK) Seminar on Digital Enterprise Technology, DET02*, September 16-17, 2002, Durham, United Kingdom: pp. 269-272.

[5] L. Monostori, A. Márkus, H. Van Brussel, E. Westkämper, "Machine learning approaches to manufacturing", *CIRP Annals*, vol. 45, no. 2, 1996, pp. 675-712.

[6] P.G. Maropoulos, "Digital Enterprise Technology – Defining Perspectives and Research Priorities", in *Proceedings of the 1st CIRP (UK) Seminar on Digital Enterprise Technology, DET02*, September 16-17, 2002, Durham, United Kingdom, pp. 3-12.

[7] S.C. Graves, A.H.G. Rinnooy Kan, P.H. Zipkin, (eds.), *Logistics of Production and Inventory*, Elsevier, 1993.

[8] E.L. Demeulemeester, W.S. Herroelen, *Project Scheduling: A Research Handbook*, Kluwer, 2002.

[9] A. Márkus, J. Váncza, T. Kis, A. Kovács, "Project Scheduling Approach to Production Planning", *CIRP Annals*, vol. 52, no. 1, 2003 (in print)

[10] F. Erdélyi, T. Tóth, J. Somló, A. Kovács, B. Kádár, A. Márkus, J. Váncza, "Production management: Taking up the challenge of integration", in *Proceedings of the Third Conference on Mechanical Engineering*, May 30-31, 2002, Budapest, Hungary, pp. 705-709.

[11] A. Márkus, J. Váncza, "Process planning with conditional and conflicting advice", *CIRP Annals*, vol. 50, no. 1, 2001, pp. 327-330.

[12] J. Váncza, A. Márkus, "A Constraint Engine for Manufacturing Process Planning", In: Walsh, T. (ed.), *Principles and Practice of Constraint Programming – CP 2001*, Springer, 2001, pp. 745–759.

[13] A. Márkus, J. Váncza, A. Kovács, "Constraint-based process planning in sheet metal bending", *CIRP Annals*, vol. 51, no. 1, 2002, pp. 425-428.

[14] L. Monostori, "A step towards intelligent manufacturing: Modeling and monitoring of manufacturing processes through artificial neural networks", *CIRP Annals*, vol. 42, no. 1, 1993, pp. 485-488.

[15] L. Monostori, Zs.J. Viharos, "Hybrid, AI- and simulation-supported optimization of process chains and production plants", *CIRP Annals*, vol. 50, no. 1, 2001, pp. 353-356.

[16] Zs.J. Viharos, L. Monostori, Z. Csongrádi, "Realizing the digital factory: monitoring of complex production systems", *Preprints of the 7th IFAC Workshop on Intelligent Manufacturing Systems*, April 6-8, 2003, Budapest, Hungary, pp. 31-36.

[17] K.N. McKay, V.C.S. Wiers, "Unifying the theory and practice of production scheduling", *Journal of Manufacturing Systems*, vol. 18, no. 4, 1999, pp. 241-255.

[18] A. Kovács, J. Váncza, B. Kádár, L. Monostori, A. Pfeiffer, "Real-life scheduling using constraint programming and simulation", *Preprints of the 7th IFAC Workshop on Intelligent Manufacturing Systems*, April 6-8, 2003, Budapest, Hungary, pp. 233-238.

[19] M. Onosato, K. Iwata, "Development of a virtual manufacturing system by integrating product models and factory models", *CIRP Annals*, vol. 42, no. 1, 1993, pp. 475-478.

[20] H. Van Brussel, J. Wyns, P. Valckenaers, L. Bongaerts, P. Peeters, “Reference architecture for holonic manufacturing systems”, *Computers in Industry*, Special Issue on Intelligent Manufacturing Systems, vol. 37, no. 3, 1998, pp. 255-276.

[21] B. Kádár, L. Monostori, E. Szelke, “An object oriented framework for developing distributed manufacturing architectures”, *Journal of Intelligent Manufacturing*, vol. 9, no. 2, April, 1998, Special Issue on Agent Based Manufacturing, Chapman & Hall, pp. 173-179.

[22] B.Cs. Csáji, B. Kádár, L. Monostori, “Improving multi-agent-based scheduling by neurodynamic programming”, *1st International Conference on Applications of Holonic and Multi-Agent systems, HoloMAS 200*3, September 1-5, 2003, Prague, Czech Republic, (in print)

[23] G. Haidegger, T. Szalay, Sz. Drozdik, “Special issues in interactive multimedia for tele-presence operations”, *Preprints of the 7th IFAC Workshop on Intelligent Manufacturing Systems*, April 6-8, 2003, Budapest, Hungary, pp. 25-30.

[24] E. Ilie-Zudor, L. Monostori, E. Kuzmina, “Constraint programming based support for production networks management”, *Preprints of the 7th IFAC Workshop on Intelligent Manufacturing Systems, April 6-8, 2003*, Budapest, Hungary, pp. 13-18.

[25] A. Márkus, T. Kis, J. Váncza, L. Monostori, “A market approach to holonic manufacturing”, *CIRP Annals*, vol. 45, no. 1, 1996, pp. 433-436.

[26] L. Monostori, J. Váncza, A. Márkus, B. Kádár, Zs.J. Viharos, “Towards the realization of Digital Enterprises”, *Proceedings of the 36th CIRP International Seminar on Manufacturing Systems, Progress in Virtual Manufacturing Systems*, June 3-5, 2003, Saarbrücken, Germany, pp. 99-106.,