SYSTEM FOR SUPPORT THE DESIGN AND OPTIMIZATION OF RECONFIGURABLE MANUFACTURING SYSTEMS

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This paper is an experimental study of the system for support the design and optimization of reconfigurable manufacturing systems (RMS), which contains from the basic components of the proposed solution. Individual parts communicate with each other and exchange information which is necessary for implement required tasks.

In addition, this paper also investigates the reconfigurable manufacturing systems, that are designed so that they may allow rapid adaptation of own capacities (market changes, product changes and to unexpected system turbulences). The aim of reconfigurable manufacturing systems is to improve production system response and thereby to provide an alternative to low-cost and high-quality production.

KEYWORDS
reconfigurable manufacturing systems, cladistics, manufacturing configurations, engineering design of production machines

1. INTRODUCTION

Innovation of production processes is now becoming an important requirement for product innovation. The time needed for production technology development increases time gap in product development.
The first who described the characteristics of reconfigurable manufacturing systems was Professor Y. Koren from the University of Michigan. In order to ensure sustainable production, we can identify the following characteristics of reconfigurable manufacturing systems:

Variability – The possibility of modifying of the manufacturing system in order to produce the proposed products.
Modularity – Decomposition of the service functions in process units, which can be interchanged within alternative production programs.
Integrability – Quick and transparent modules integration (mechanical, information and control interfaces).
Customisation – Design of the manufacturing system flexibility or machine around a specific product family.
Scalability – Changes in the current production capacity by adding or removing of system components in order to increase current performance.
Convertibility – Change in the current functionality of used components and control systems.
Reusability – Re-use of modules in the system elements. System elements, which are ended the life due to excessive wear.
Energy efficiency – Achieving of energy efficient processes by interchanging of the system components and change the system performance [Coliseum 2011].
Environmental safety – Use of alternative energy sources for production and elimination of waste by using of the advanced materials and modern technology [Krajcovic 2013].
Diagnosis – Automatic monitoring of the current state of system components and their control. The purpose is in diagnosing and detecting of potential errors in order to initializing preventive corrective actions and system reconfiguration. Y. Koren has developt new approchase how to expand capacity and funcionality of manufacturing manufacturing system and called him a reconfigurable manufacturing system. Relationship between capacity and functionality change in the reconfigurable manufacturing systems is shown in Fig. 1.

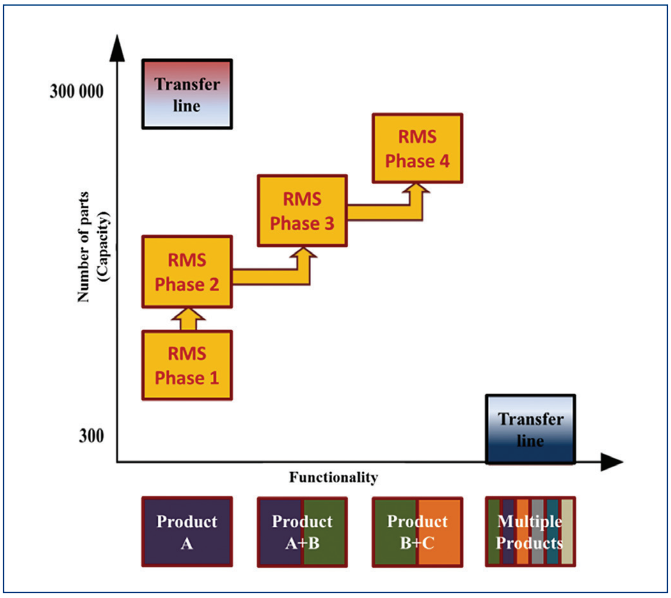

Figure 1. Capacity and functionality change in the reconfigurable manufacturing system (Koren, 2011)

The purpose of reconfigurable manufacturing systems is a rapid adjustment of production capacity and functionality with respect to quick response to generating circumstances. The main task of manufacturing system reconfigurability lies in hardware and software components changing. The requests for initialization of reconfigurable activities are listed in Table 1.

Requests for initialization of reconfigurable activities	Reconfigurable activities
New product or system	Transformation of existing system
Addition of a new product (ending of production of current product, start-on the production of new product or simultaneous production of both types)	The change of functionality
Demand changes (volume)	Change of capacity
Request on improving the manufacturing quality and system productivity	Integration of new technology or component to current system
Disposal of a product and reusing of system components	Integration of models being used, with new models

Table 1. Requirements for initializing system reconfiguration

Manufacturing enterprises must develop common integrable environment, which will be based on usual standards. Within the presented integration development environment reconfiguration bases, the constructive methods and module integration must be clearly defined [Gaso 2009]. Set of methods, theories and rules will form a knowledge base, which will serve for quick designing, building and quick ramp-up of designed manufacturing system [Gregor 2008]. Quick design of RMS or new manufacturing configuration requires the following methods:

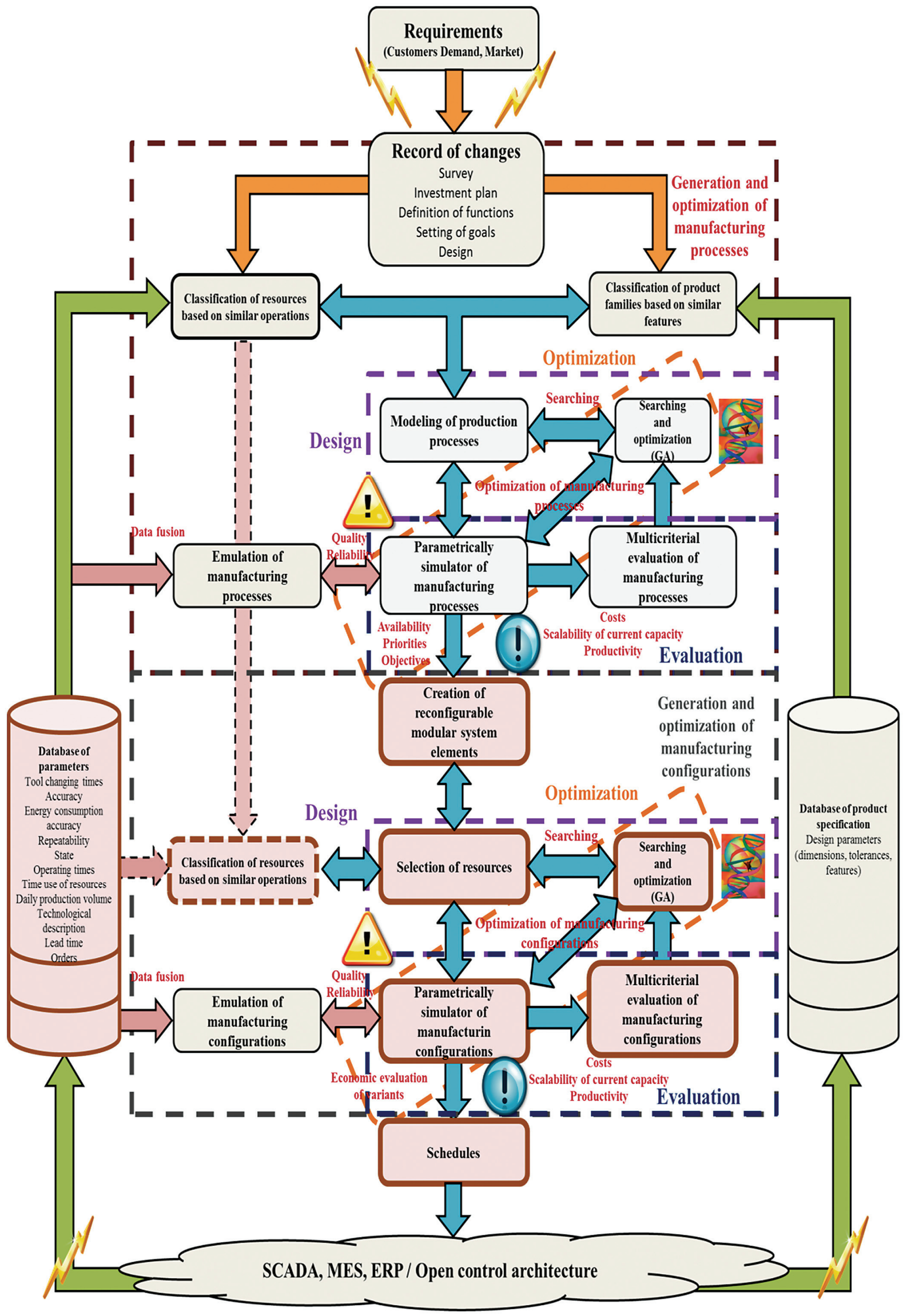

Figure 2. DAOSSORMS – Design and optimization support system of reconfigurable manufacturing system

- exerted rules for system configuration creation,
- economic performance modelling (extensive production systems) [Kohar 2013],
- the rules of system reliability,
- the production configuration managing rules,
- the rules and standards for achieving energy efficiency,
- the priority rules for orders fulfillment [Micietova 2014].

2. EXPERIMENTS

Experiments were carried out on the system for support the design and optimization of reconfigurable manufacturing systems (DAOSSORMS) that is shown in Fig. 2, which contains from the basic components of the proposed solution. *The first step in the design of reconfigurable manufacturing systems is necessary that the information system must be able to capture changes associated with fluctuations in demand, changing customer requirements and the changes on an unstable market. The next step is to classify resources and products on the basis of relative similarity. Before the search of suitable model it is necessary to harmonize evolutionary models.* Given approach leads to reducing the computational demands on memory.

The parameters for experiments are descripted as time, cost and energy consumption. The first stage of DAOSSORMS (Fig. 2) is characterized by the formation of personal evolutionary models of manufacturing systems and products, which are realized on the basis of the available parameters.

Assumption is that this step will be time-consuming within analytical modelling of manufacturing processes.

In the second stage it is necessary to look identical models of manufacturing systems and product parts. The issue can be addressed through the similarity analysis (mutual combinations).

This stage is much less computationally demanding than the previous. The next stage in process modelling is to preserve the possibility of further evolution of an existing proposal for the introduction of new product parts or resources.

Due to the fact it is necessary to test the proposed models and find the best solution for further integration. In the fourth phase should be ensured to prevent the identification of non-identical parameter in the designed models. It means that in manufacturing system design is taken into consideration identical parameters. For example one feature 1 is equal to 1 and capability of the production machine is equal to 1. Thus, the ability of the production machine belongs to product feature. This process is based on searching. This approach is particularly necessary to choose at very complex models (for X species may exist solution $X + X_n$).

Update of each model depends on the number of non-relevant solutions and pairs of species. In the identification of non-relevant pairs of species A and B must be reconfigured model so that it can be introduce new predicted product components and technical systems. The final phase of modelling of manufacturing processes is the reduction of relations between products and technical systems. In order to reduce the association is to generate relationships between resources and product patterns.

2.1 RMS – EFFECTIVE WEAPON AGAINST DEMAND FLUCTUATION

Within the formation of optimal production configurations will be necessary due to changes in demand to revise the total number of possible configurations which may occur in the system [Rakyta 2010]. The calculation is dependent on the number of currently available resources, planned daily production volume, planned time unit for the production of piece, daily work fund of equipment and reliability of equipment. Then used simple conversion $2^{n.equipment-1}$ specifies the total number of possible configurations. The nubmer of configuration is calculated as:

$$K = \sum_{m=1}^{N} \binom{n-1}{m-1} = 2 \wedge (\text{n.equipment} - 1)$$

n – Number of machines
m – Arrangement approach (number of levels)
K – Number of configurations

Individual configurations are then simulate in parametric simulator of manufacturing configurations and evaluated on the basis of set criteria.

Optimal variants will be selected with the assistance of a genetic algorithm, which based on the evaluation criteria reduced the initial population of solutions. Integral part of the system is the classification of resources based on similar operations.

This step will allow us to create different groupings of resources and by the way, will facilitate the work in finding the optimum material flow within the different configurations. Upon reaching the limit values must the evaluation subsystem highlight the lack of capacity in various configurations and after then propose a new solution. By forming of new manufacturing configurations is necessary to count with investment cost which consists from difficulty of physical rebuilding (e.g. modular construction machines). The approach for forming the manufacturing configurations is shown in Fig. 3.

Within this approach may be available machines consisting from different modules assembled in different configurations and offer expanded functions. It means that if the operator changes the input parameter of the machine, then the equipment must quick adapt their capacity. Equipment in reconfigurable manufacturing systems must offer the required functionality only if all of them are programmed around product family which we want in the system produce. This approach is requiring also reconfigurability of workforce, which must be informed about coming change.

Reconfiguration in this sense takes place on the basis of changes in work tasks of individual operators. Similar principles apply in assembly systems.

3. RESULTS OF EXPERIMENTS

Within the reconfigurable manufacturing systems is the most important phase of production plan compilation, which is focused on identifying dependencies between patterns of products and technological units located in the presented manufacturing system.

Profile of part / Part	Cylinder (1.)	Prism (2.)	Thread/ Chamfer (3.)	Other profiles (4.)	Complex profiles (5.)
Part 1.	1	0	1	1	0
Part 2.	1	0	0	0	0
Part 3.	1	1	1	1	1
Part 4.	1	0	0	0	0
Part 5.	1	1	1	1	0
Part 6.	1	1	1	1	0

Table 2. Characteristics of the machined parts

The best method that can be used in this approach is cladistics. Cladistics is presented as an evolutionary method and as the most appropriate method for the formation of new generations of products and manufacturing systems and association between them. This principle is based on the formation of evolutionary models by using of genetic algorithms. Characteristics of the machined parts are shown in Table 2 and characteristics of the manufacturing technologies are shown in Table 3.

Machine configuration/ Set	Parts on the spindle (1.)	Milling (2.)	CNC (3.)	Magazine/ Turret (4.)	Multi-axis (5.)
Lathe with rotating head	1	0	0	1	0
Lathe	1	0	0	0	0
3-axis turning center	1	1	1	1	0
2-axis CNC lathe	1	0	1	0	0
CNC machining center	1	0	1	1	0
5-axis machining center	1	1	1	1	1

Table 3. Characteristics of the manufacturing technologies

Within forming of the evolution branches is necessary to ensure the development of approximately equal branches. Due to the mutual similarity of branches is possible to ensure faster and more efficient development of new generations. Formation of new generations of manufacturing configuration is shown in Fig. 4.

It is also necessary to identify the properties of evolutionary models of manufacturing systems and product features. Identification is performed on the basis of mutual kinship and individual relations between evolutionary branches. The new generation of manufacturing systems and products is shown in Table 4. The next step is to identify the most appropriate configuration. This identification is performed on the basis of individual branch similarity which is expressed by the number 1 or 0. Required generation of manufacturing configuration

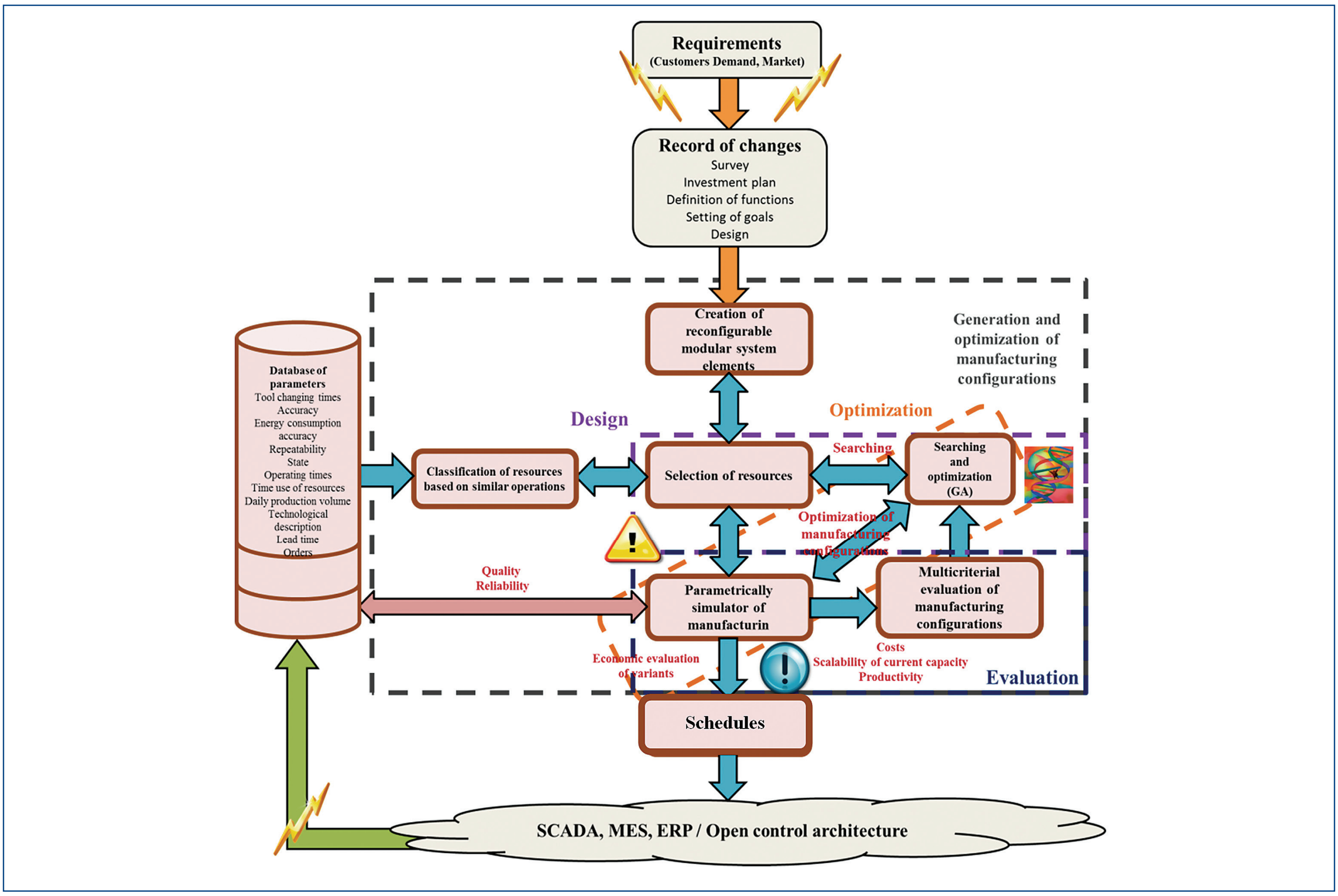

Figure 3. The approach for forming the manufacturing configurations

is not possible to compile when it is not possible to distinguish kinship within individual branches which will vouch for the manufacture of the proposed product.

From the Table 4 is clear that the most appropriate configuration of the solution is generated system Cp1 -> Pf1. Cp is an acronym for manufacturing system capability and Pf is an acronym for product feature. Where:

Cp1 -> Pf1, Pf2, Pf3, Pf4, Pf5;
Cp1 -> Pf1 = opt.;
Cp2 -> Pf1, Pf2 Pf3, Pf4, Pf5;
Cp2 -> Pf2;
Cp3 -> Pf1, Pf2, Pf3, Pf4 Pf5;
Cp3 = Pf 4 = opt.;
Cp4 -> Pf1, Pf2, Pf3, Pf4, Pf5;
Cp4 = Pf3 = opt.;
Cp5 -> Pf1, Pf2, Pf3, Pf4, Pf5;
Cp5 = Pf5 = opt.;

The term suboptimal variant represents cost, time and energy best solution.

4. CONCLUSIONS

For an suboptimal setting of the manufacturing configuration is necessary to use computer simulation through which it can be identified optimal time for the production, production volumes, production quality and system reliability. The objective is simple integration of product variants based on customer needs and consequently the effective implementation of mass production through the economics of scale which will ensure the production of affordable product. It is well known that the reduction of unit cost is realized by increased volumes of production.

	Functional branch	Capabilities of MS – Cp					Product features – Pf				
		1.	2.	3.	4.	5.	1.	2.	3.	4.	5.
Interdependencies	A	1	0	0	0	0	1	0	0	0	0
	B	1	0	0	0	0	1	0	0	0	0
	C	1	0	0	1	0	1	0	1	0	0
	D	1	0	1	0	0	1	0	0	1	0
	E	1	0	1	0	0	1	0	0	1	0
	F	1	0	1	1	0	1	0	1	1	0
	G	1	0	1	1	0	1	0	1	1	0
	H	1	1	1	1	0	1	1	1	1	0
	I	1	1	1	1	0	1	1	1	1	0
	J	1	1	1	1	1	1	1	1	1	1

Table 4. Dependences between capabilities of the manufacturing systems and product features

Three features – capacity, functionality, and cost – are what differentiate the types of manufacturing systems. In the future reconfigurable manufacturing system (RMS) will constitute a new class of systems characterized by adjustable structure and design focus.

Economy of scale can be achieved if the production volume increases and when we have downward trend in production costs for each unit [Magvasi 2013].

Realization of the simultaneous production of multiple products will require cost-effectiveness [Slamkova 2010].

The customer must be integrated into the design process, which consists from the conceptual design and product development. Process must be initialized by the expression of the requirement or mutual cooperation, which consists in a joint effort to design product configuration.

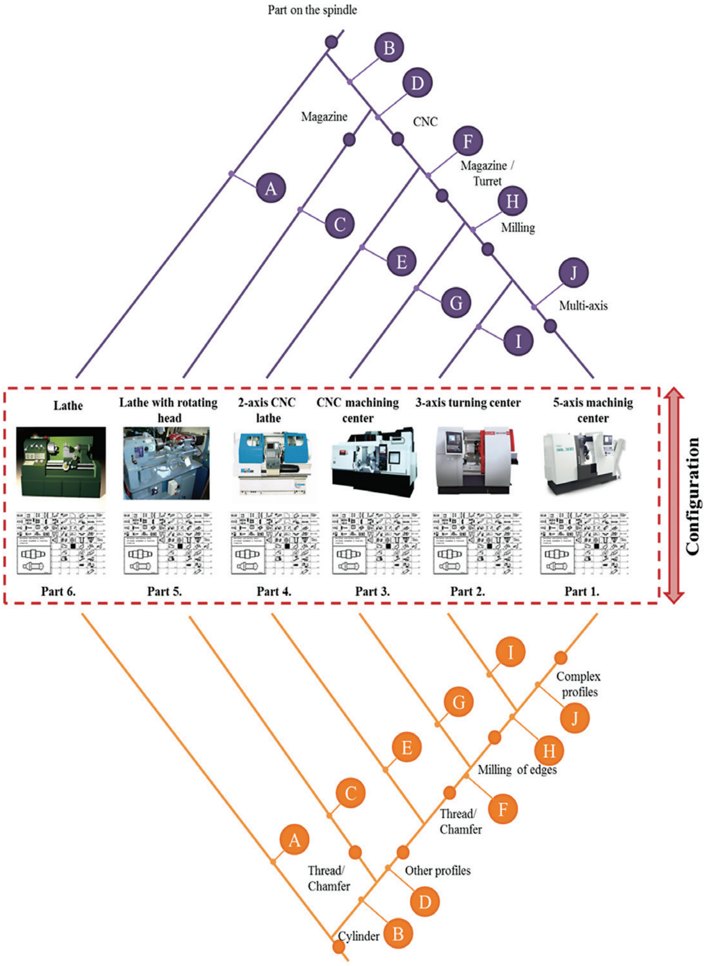

Figure 4. Formation of new generation of manufacturing configurations

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