PLANNING MANUFACTURING PROCESSES OF SURFACE FORMING WITHIN INDUSTRY 4.0

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The article explores essential prerequisites and effects for automated processes of surface forming in planning manufacturing processes within Industry 4.0. Based on authors' practical experience and profound knowledge, they describe the adequate use of industrial robots and handlers for automated manufacturing processes. They in depth analyse methods and structures of handling operations and their application in automation of surface forming. Moreover, they give examples of handling methods and structures of operations in regard to the settings of production facility. A close attention is paid to their own structure of manufacturing process and its characteristics. Furthermore, the production system is divided into individual subsystems, and also, basic functional bonds are analysed. Eventually, production systems are divided according to the variety of their technological competences. The suggested article fits in the concept of solutions within Industry 4.0, namely in regard to its design, digitalization and data collection.

KEYWORDS

production process, Industry 4.0, methods and structure of operations

1 INTRODUCTION

Automation of production processes brings in increasing requirements for engineering works in the preparation of production, which mainly reflects in tightening deadlines of implementing research findings in practice, planning manufacturing processes and economics of manufacturing processes. Automation of engineer works is associated with an extensive use of mathematic methods based on science, research and engineering practice inclination to mathematics. As a matter of fact, mathematics is applied in calculating particular operations and employing mathematic methods in order to formulate them. These methods include: operation analysis and automatic computers, set theories, structure theories, algorithm, language theories etc. [Blascik 1989].

In order to successfully develop machinery production, industrial robots and handlers should be largely applied. Applying robots and handlers in the manufacturing process enables the human factor to be replaced even without more substantial changes of the current production structure; thus, they become key elements of automation. Subject to existing IRaH (industrial robots and handlers), solid foundations for their mass employment have been laid basically in all machinery technologies, which may be considered as a transferring phase to a fully automated facility.

2 METHODS AND STRUCTURE OF HANDLING OPERATIONS

New approaches of exploring technological operations, mostly based on development of structures of operations, may be implemented in regard to the composition of their elements which take part in the operation. The general model looks as follows [Blascik 1989]:

$$\check{C} - S_h^l N_m^l P_m^l - O, \tag{1}$$

Where

Č – human (operator)

O – object of the handling process

S, N, P – sets of manufacturing machines, tools and products within the particular technological operation

h, n, m – indicators of the quantitative value of each set

l – determinant of qualitative indicators of each production means

On the grounds of approaches to a technological operation in the handling operation, a handling method and structure may be distinguished. Operational functions are associated with the handling method, which informs about the position change of the object, its positioning etc. Tab. 1 suggests the division of automated handling methods. The implementation of the structure of the handling operation may be defined by the timing of actions and involved components.

The development of structures of handling operations may be based on using co-dominant space of the production facility in the surface forming technology; i.e. shortening the actual time of handling operations of the end-to-end robot component. It mostly concerns an increasing amount of overlapping handling operations with the technological ones. This principle lays down a development of time structures of handling operations for stimulating the manufacturing process [Blascik 1989].

The time structure of the operation results from the division of operating time into departments associated with functionally integrated technological and auxiliary operations. Operating time in the technological operation may be defined as follows:

$$t = \sum t_h + \sum t_v^p + \sum t_v^z + \sum t_v^h - \sum \tau \ [min], \tag{2}$$

Where

t_h—main time in minutes,

t_v^p —secondary time associated with the object of technological process in minutes,

t_v^z—secondary time associated with technological facilities in minutes,

t_v^h—secondary time associated with tools used in the technological process in minutes,

τ—overlapped time in minutes,

t_{nn} - time for facility settings (change)

t_{np} - time for product settings (change)

Table 1. Examples of handling methods

Handling operation	Method	Technical implementation
Gripping and positioning of object	Mechanically under elastic magnetic force	by fingers, pliers, clamp etc. suction gripper, magnetic gripper, elastic gripper
Relocation of object	gravity power presser cinematic mechanism	gravity conveyor, slides, hydraulic and pneumatic facilities, industrial robots and handlers
Position	mechanically visually by touch	stacks, robot-vision, visual systems, tactical sensors and robots

Table2. Classification of operations structures in regard to the settings of production facilities

Settings	**Conditions**							
Facility settings	$t_{nn} \neq 0$				$t_{nn} = 0$			
Product settings	$t_{np} \neq 0$		$t_{np} = 0$		$t_{np} \neq 0$		$t_{np} = 0$	
Control system settings	$t_{nr} \neq 0$	$t_{nr} = 0$	$t_{nr} \neq 0$	$t_{nr} = 0$	$t_{nr} \neq 0$	$t_{nr} = 0$	$t_{nr} \neq 0$	$t_{nr} = 0$
Time settings	$t_{nz} = t_{np} + t_{nr}$	$t_{nz} = t_{nn} + t_{np}$	$t_{nz} = t_{nn} + t_{nr}$	$t_{nz} = t_{nn}$	$t_{nz} = t_{np} + t_{nr}$	$t_{nz} = t_{np}$	$t_{nz} = t_{nr}$	$t_{nz} = 0$
Manufacturing processes	1	2	3	4	5	6	7	8

Principles of organizing models of operational structures according to the time settings illustrated in Tab 2 have been worked out in many professional works and will be applied in machining technology. Based on these works, it is possible to make a conceptual model of the time structure of technological operations as follows:

- From class of operations
- From group of operations
- From subgroup of operations
- From organizing sequences of operations and their integration into one, or more currents

Having said that, the structure of handling operations in the technology of surface forming may be defined as follows:

$$T - Z_m^k P_n^k N_h^k - V, \qquad (3)$$

Where
T—human — performer,
Z —handling facility (robot)
P—handling product (arm of the robot)
N —handling tool (robot suction cup)

t_{nz} - time for control system settings
t_{nr}- time for time settings; change of the software

V — product – object of the handling process
m, *n, h* — quantitative indicators of the number of facilities, products and tools
k — qualitative indicator defining the characteristic of handling facilities (degree of innovation).

Four classes are distinguished within the structural model of handling operations. Before we classify handling operations themselves, it is necessary to introduce essential features by which handling facilities, products and tools may be characterized. The degree of innovation may be specified as follows:

- new handling devices
- extended handling devices (renewal)
- old handling devices

Each part may be further characterized by the degree of mechanization, automation, flexibility, reliability etc. in regard to the distinctive character of the handling operation.
The classification of handling operations proceeds as follows:

1. Non-element class is characterized by operations using neither handling facilities, nor products or tools; i.e. m * 0, n ** 0, h *** 0.
2. One-element class is characterized by operations using one type of handling devices.
3. Two-element class is characterized by operations using two types of handling devices.
4. Three-element class is characterized by operations using all types of handling devices – facilities, products and tools.

In regard to the technology of surface forming for the development of production automation, it is necessary to channel planning of handling operations into 3rd and 4th class. Two and three-element classes may be characterized by applying automation and robotizing at the highest degree of innovation of handling devices.

3 FUNCTIONAL STRUCTURE OF THE MANUFACTURING PROCESS

Manufacturing process may be characterized as an activity during which the manufacturing object changes into a finished product; within this process, workers convert a manufacturing object into a finished product by means of manufacturing devices, the process of which is associated with the modern manufacturing technology.

Technological workplaces of surface forming may be characterized by direct relations between components as follows:

- input and output relations of individual components
- degree of mechanization and automation
- degree of standardization
- Spatial relations of individual components etc.

Function of the technological workplace may be characterized by following indicators:

- production
- quality of the technological processing
- economy
- Reliability etc.

Suggested technological and functional characteristics of the technological workplace may be considered identical. Therefore, with respect to ATW (Automated Technological Workplaces) planning, these workplaces should be divided into subsystems as follows:

- technological systems
- inter-operational transport and storage
- operational handling
- energy sources and distribution
- measurements and monitoring
- controlling

In order for ATW and APS (Automated Production Systems) to be working properly with IRaH, it is necessary to define functional relations, which may be represented by following functional structures[Dalakjan 1986]:

1. Free arrangement of workplace components (production facilities) concerning a rather complex system of technological processing and controls.
2. Functional (technological) arrangement of workplace components concerning a considerable simplification comparing to a loose arrangement.
3. Modular arrangement of workplace components concerning a set of equal multi-purpose technological and handling subsystems.
4. Cellular arrangement of workplace components concerning the target structure of construction of highly automated APS and IRaH where surplus elements are eliminated and internal relations are optimized.

In regard to the variety of technological possibilities, APS may be divided as depicted in Figure 1:

- single-stage
- multi-stage
- combined

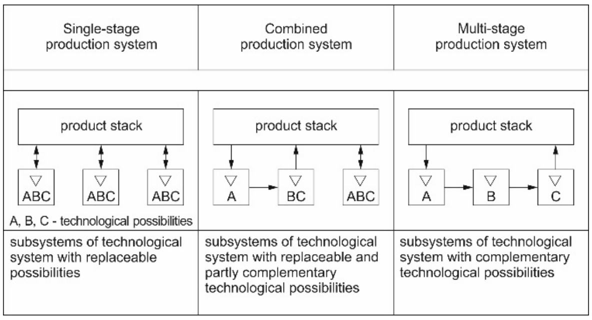


Figure 1. Division of production systems regarding varieties of technological possibilities

Transport and storage are secured by the subsystem of inter-operational transport and storage, which also controls accumulation of objects within the technological process, tools and other supplementary material.

The way of classifying storehouses into subsystems of the technological systems and choosing objects of technological processing on transport and storage in APS are depicted in Figure 2. Free arrangement is the most important way as objects from the storehouse may be chosen randomly.

Ways of transporting objects within the technological processing of production systems to subsystems of technological system may be:

–

nside the subsystem workspace, i.e. internal connection

–

utside the subsystem workspace, i.e. external connection

Classifying ways of transport is suggested in Figure 3.

Possibilities of classifying storehouses and tool stacks to subsystem of the technological system within APS are of a major importance to the technology of surface forming and are depicted in Fig. 4[Kmec 2015a].

In regard to other subsystems, they show functional characteristics which are generally applicable also in other technologies[Dalakjan 1986].

The issue of functional structures of production systems in IRaH regarding subsystem synthesis may be classified as follows:

1. Organizing subsystems of the technological system in APS
2. Classifying storehouses of objects to subsystems of the technological system

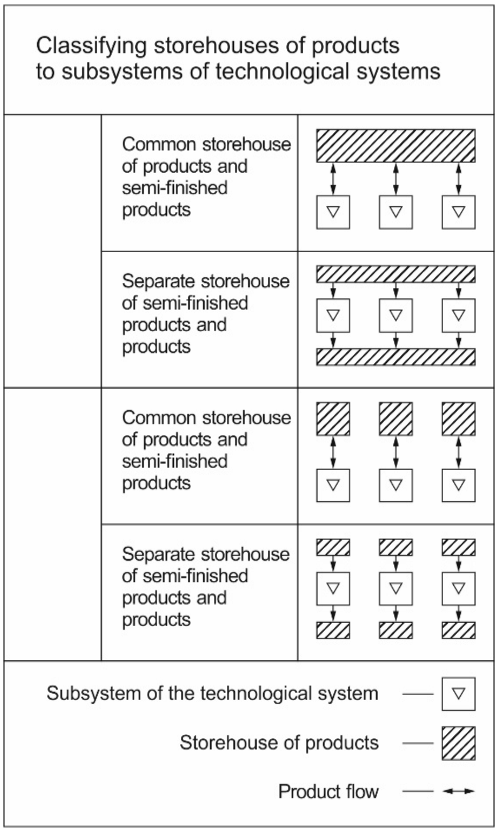


Figure 2. Ways of classifying storehouses of products to subsystems of the technological system

i

Parallel principle	Serial (link) principle	Symbolic depiction
Way of transport with separate input and output	internal connection	
Way of transport with common input and output	external connection with common input and output	
	External connection with separate input and output	

o

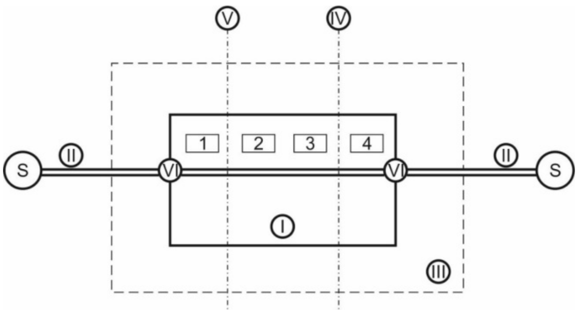
Figure 3. Ways of transport of products and classification to subsystem of the technological system

3. Classifying ways of transporting objects to subsystems of the technological system
4. Classifying storehouses of objects to ways of transporting objects
5. Type of storehouse construction

In regard to the technology of surface forming, suggested classifications need to be supplied with classified tool storehouses to subsystems of the technological system.

Group of comprehensive automated technological workplaces and automated production systems with IRaH tackles assigned technological tasks which should be fulfilled within Industry 4.0.

With respect to automation of production processes in mechanical engineering using industrial robots and handlers, it is necessary to consider a comprehensive automated technological workplace – as an elaborate system.



Classifying tool storehouses to subsystem of the technological system in automated production systems	classifying principles: subsystem of the technological system; tool storehouse; tool exchange	amount of tools for the identical techno-logical operation	equipment time (exchange time) for a random tool
Central storehouse		small	long
Central tool storehouse with decentralized exchange stacks		medium	long for tools in the central storehouse; short for tools in exchange stacks
Central tool storehouse with decentralized permanent stacks		big	long for tools in the central storehouse; short for tools of permanent stacks
Decentralized tool stack		very big	short

Figure 4. Principles of classifying storehouses and tool stacks to subsystems of the technological system in production systems

Figure 5 suggests a scheme of a comprehensive automated technological workplace in which individual components, bound subsystems and their mutual relations are depicted.

Grouping of comprehensive automated technological workplaces with a central automated control allows creating automated production systems on different technological levels (in a direct correlation of production tasks with the degree of automation of individual manufacturing, handling and technological activities).

Model of the automated production system is illustrated in Fig. 6 [Kmec 2015b].

The range of activities and functions of individual subsystems of the automated production system is defined as follows:

- *Subsystem of the technological system* involves a set of elements (machines, tools or products) which participate in the change of physical-mechanical and geometrical characteristics of the processed object (workpiece).

- *Subsystem of inter-operational transport and storage* involves means of storage and transport which implement the material flow, workpieces, tools, products, waste etc. into comprehensive automated technological workplaces.

- *Subsystem of measurement and control* concerns monitoring and signalling of technological and handling operations; i.e. measuring the accuracy of particular characteristics of the workpiece, position of production and auxiliary facilities.

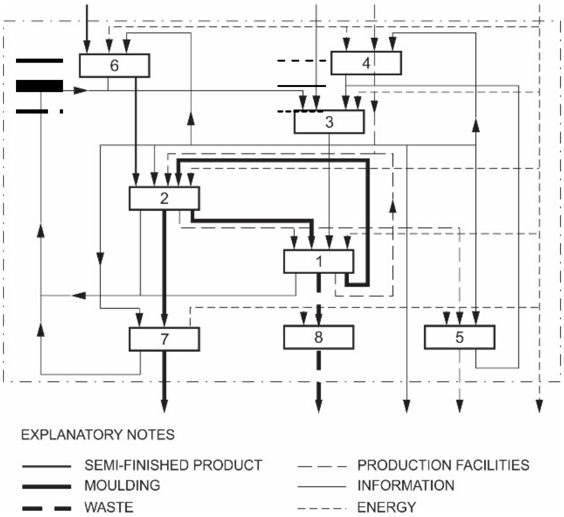


Figure 5. System of a complex automated technological workplace using PRaM

1 - manufacturing equipment, 2 - industrial robot or manipulator, 3 - control system, 4 - input of ATP production aids, 5 - output of ATP production aids, 6 - ATP output, 7 ATP input, 8 waste from ATP

Figure 6. Model of an automated production system

I – technological system, II – transport and storage, III – measurement and monitoring, IV – energy sources and distribution, V – controlling, VI – operative handling 1 – machine, 2 – tool, 3 – product, 4 – material, S – storehouse

- *Subsystem of sources and energy distribution* refers to a set of sources, distributions and regulation elements ranging from central sources to local inputs of individual devices.

- *Subsystem of control* deals with a set of elements which secure controlling of technological, handling and manufacturing process in the automated production system and integrate other subsystems.

- *Subsystem of operative handling* involves a set of technological devices providing operative handling in comprehensive automated technological workplaces with objects of technological processing and tools. It includes industrial robots, handling devices and other auxiliary handling tools [Blascik 1989].

It is possible to suppose that construction of automated production systems will be implemented in different horizontal divisions (degree of integration) and vertical divisions (degree of automation). The degree of integration concerns qualitative formulation of technological and production tasks. The degree of automation deals with extent of automation of individual controlling, technological and handling activities [Kmec 2015].

4 CONCLUSION

Automation of contemporary continual technological processes successfully resolves problems of a rapid development of discreet mechanical technologies. There are issues of saving workforce in low-series productions, material handling, distribution and services. These efforts stimulate a rapid development of CNC machines, production departments, industrial robots and handlers, control systems, new distributional networks etc., which were developed in order to run fully automated factories and which enhance the quality of products within the manufacturing process with a view to supporting intentions of Industrial Revolution 0.4.

Suggested approaches summarize recent findings which should be implemented in the next period of planning automated and robotized workplaces. In addition, the article focuses on more precise approaches towards planning robotized workplaces. Nowadays, these trends suggest huge efforts towards planning manufacturing processes, apart from others, in regard to time, handling, functional and technological structures.

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